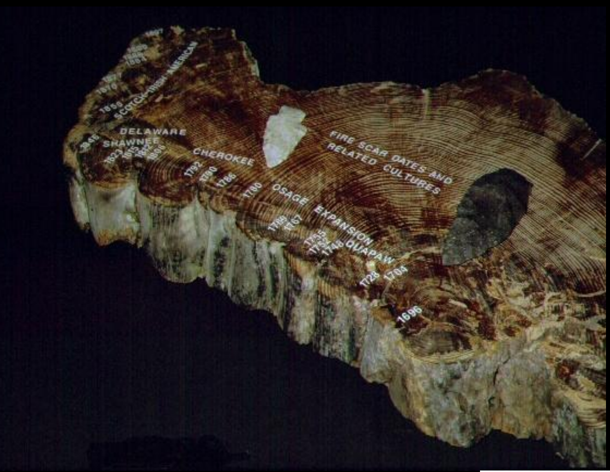
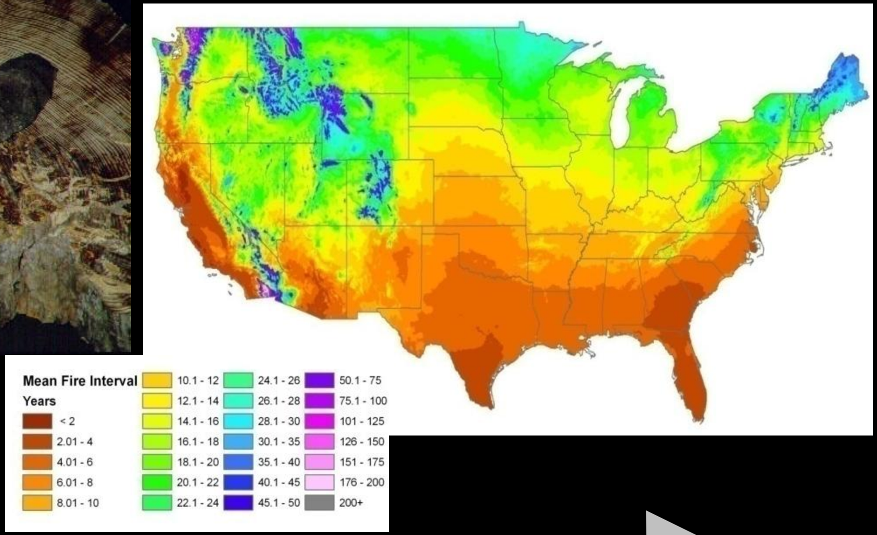
FUTURE CONTINENTAL AND GLOBAL CLIMATE FORCING OF FIRE FREQUENCY

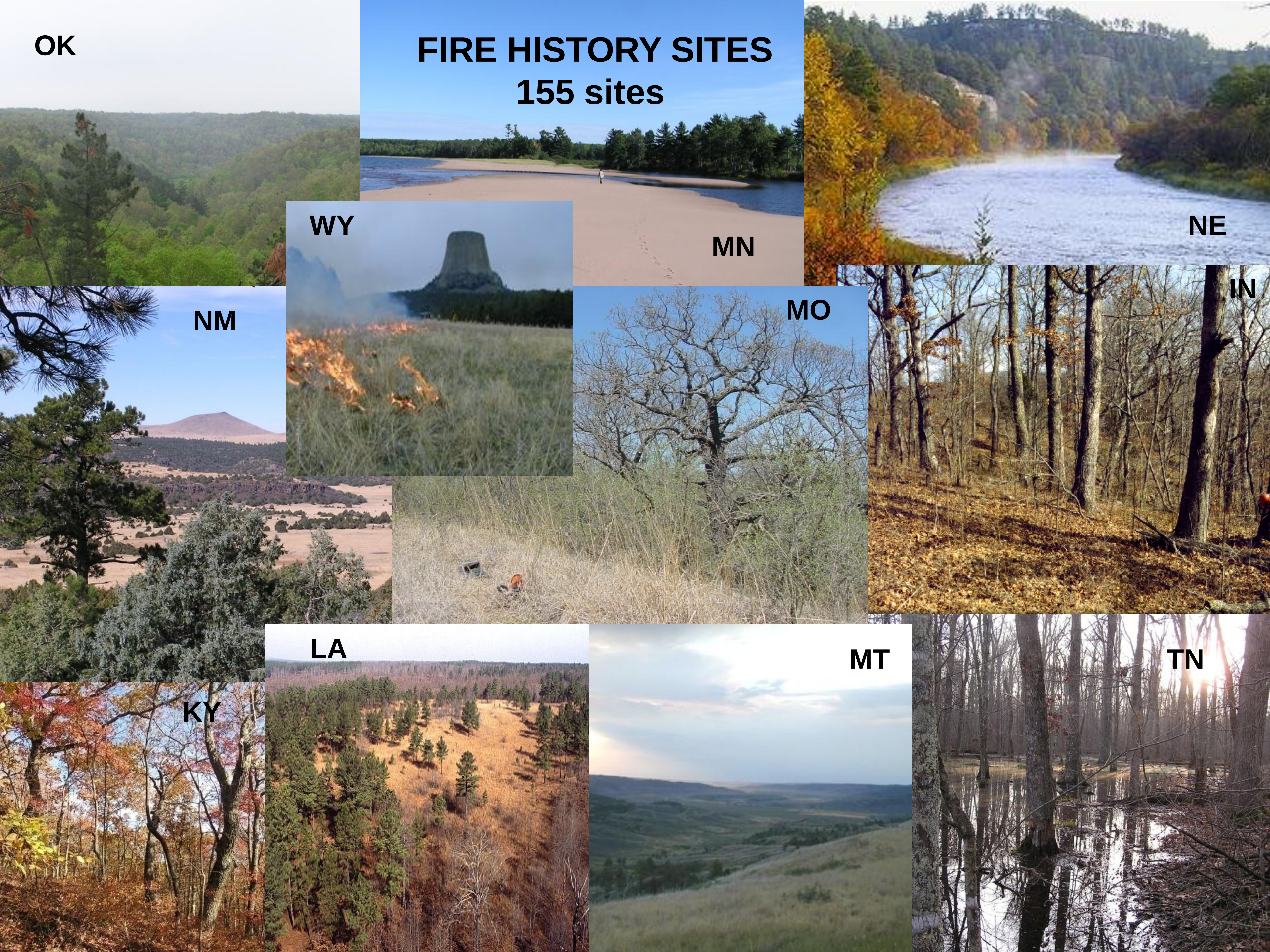




$$MFI = C\mathbf{exp}^{(-\boldsymbol{temp})\ \ (+\boldsymbol{1/moisti})\ \ (-\boldsymbol{pop})\ \ (+\boldsymbol{precip}))}$$

Collaborators: Richard Guyette, Michael Stambaugh, Daniel Dey, and Rose-Marie Muzika.
University of Missouri and Northern Research Station

FIRE HISTORY SITES
155 sites



Data background for PC2FM

(Physical Chemistry Fire Frequency Model)

A mechanistic model with statistical validation

Calibration of mechanistic model variables with historic fire interval data

Data

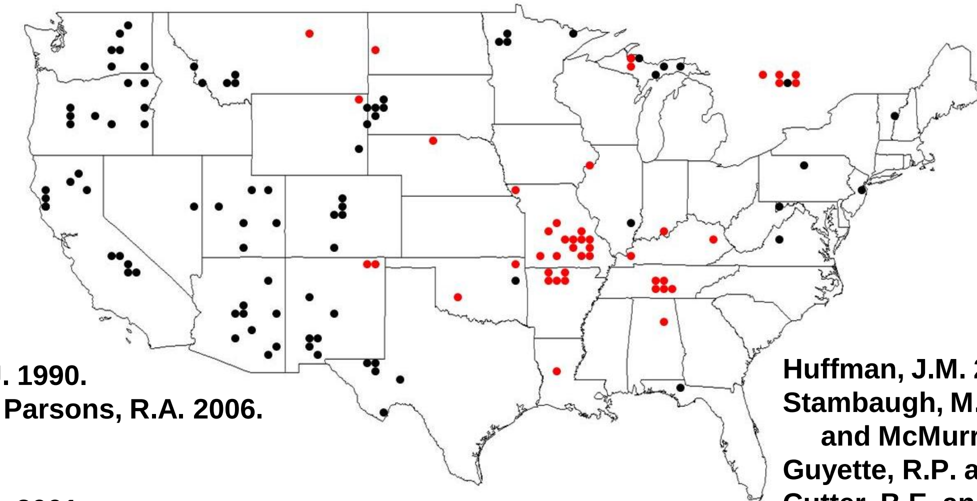
a. fire interval data from 156 fire studies in 38 states (146 fire scar, 3 charcoal, 8 expert estimates), pre-Euro American settlement periods, average site area 1.3 km^2

b. about 1700 tree and 14,000 fire scars

c. PRISM climate data for mapping, sites ([1970 to 2000] -.4^{o}C)

d. Anthropological data on human population

Fire history authors, publications, IMPD data, and site location



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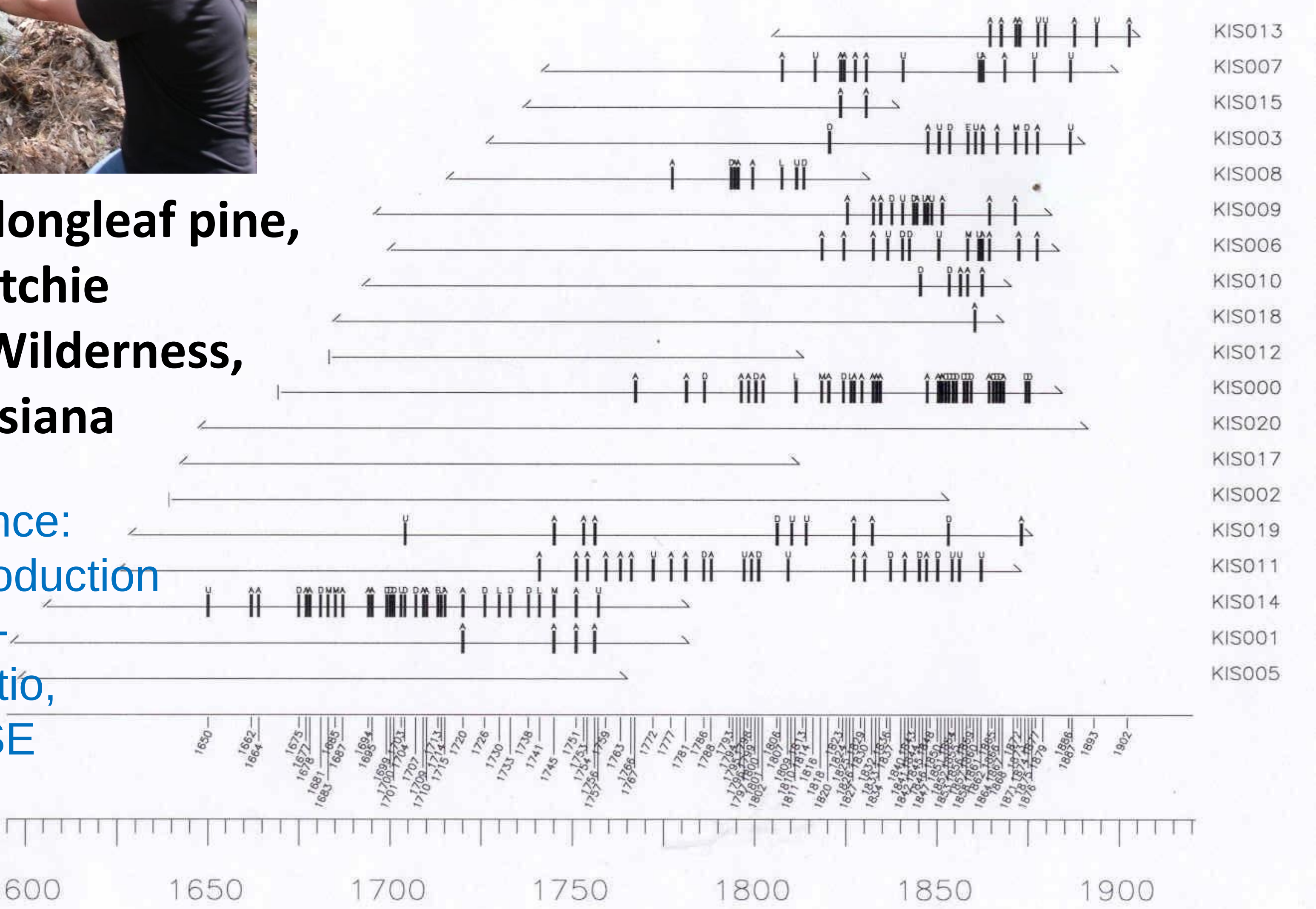
Sites with a broad range of climate are necessary for model calibration and validation

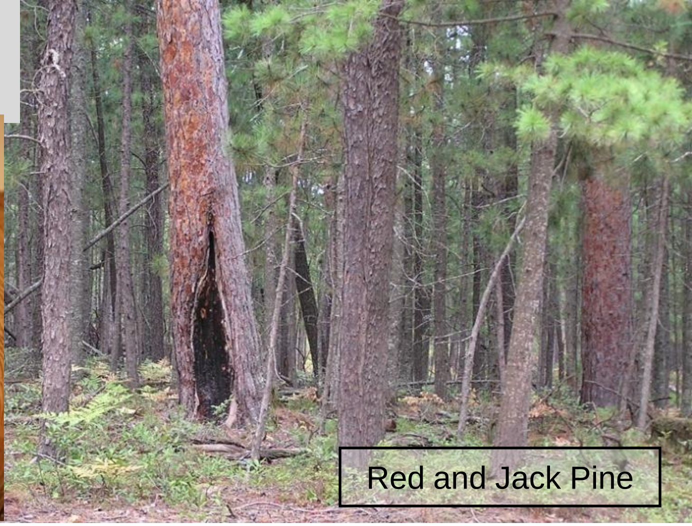
Fire history, longleaf pine, Kisatchie National Wilderness, Louisiana



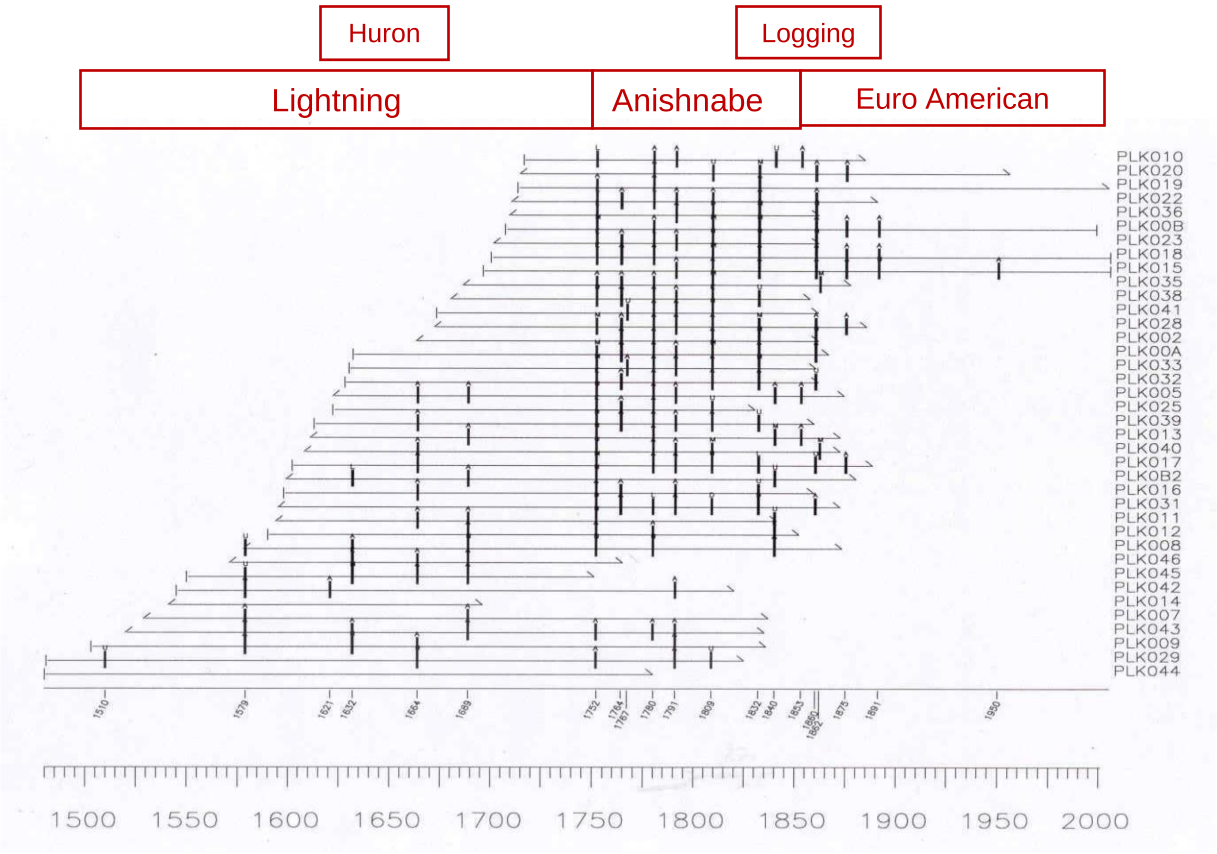
Model importance:
1. rapid fuel production
2. temperature-precipitation ratio,
3. Gulf Coast SE location

Huron Mountains, Lake Superior, Burnt Pine River, Michigan

Red pine stump, 1632 -1862, 8 scars, MFI = 34 years



Red and Jack Pine



Modeling importance:

1. Low elevation, cold, deep snow climate
2. Lightning to human fire regimes in 1752
3. Native American burning for blueberries
4. Low elevation land-water interface

Model background for PC2FM

(Physical Chemistry Fire Frequency Model)

A mechanistic model with statistical validation

- **Variables**
- **dependent variable:**

  mean fire intervals
- **independent variables:**

  1. annual mean max temperature

  2. annual total precipitation

  3. 1/(precipitation/temperature)

  4. human population density
- no lightning in model yet
- no vegetation types

Scaling reaction rates from the laboratory to the landscape

In the lab: A_o is the molecular collision frequency. On the landscape: A_o has much larger distances and structures and is affected by fuel concentration, oxygen, wind, and elevation

In the lab: E_a (activation energy) is the energy required to begin a reaction. thru ignitions by humans. On the landscape: E_a is affected by fuel moisture and the energy of ignitions. In both the lab and landscape humans have knowledge of the energy requirements of E_a

In the lab: it's the temperature of the reactants. On the landscape: the average temperature of the reactants (fuels and O_2).

In the lab: *k* is in seconds decreases with *T*,
On the landscape: *k* is scaled to years and mean fire intervals as *1/ MFI*.

$$\boldsymbol{k = A_o \exp^{-Ea/RT}}$$

Svante Arrhenius
Noble Prize 1903,
physical chemistry

where: the mean fire interval (MFI) is 1/k,

k = rate constant for wildland fires in s^{-1} or yrs^{-1}

A_o = molecular collisions rates

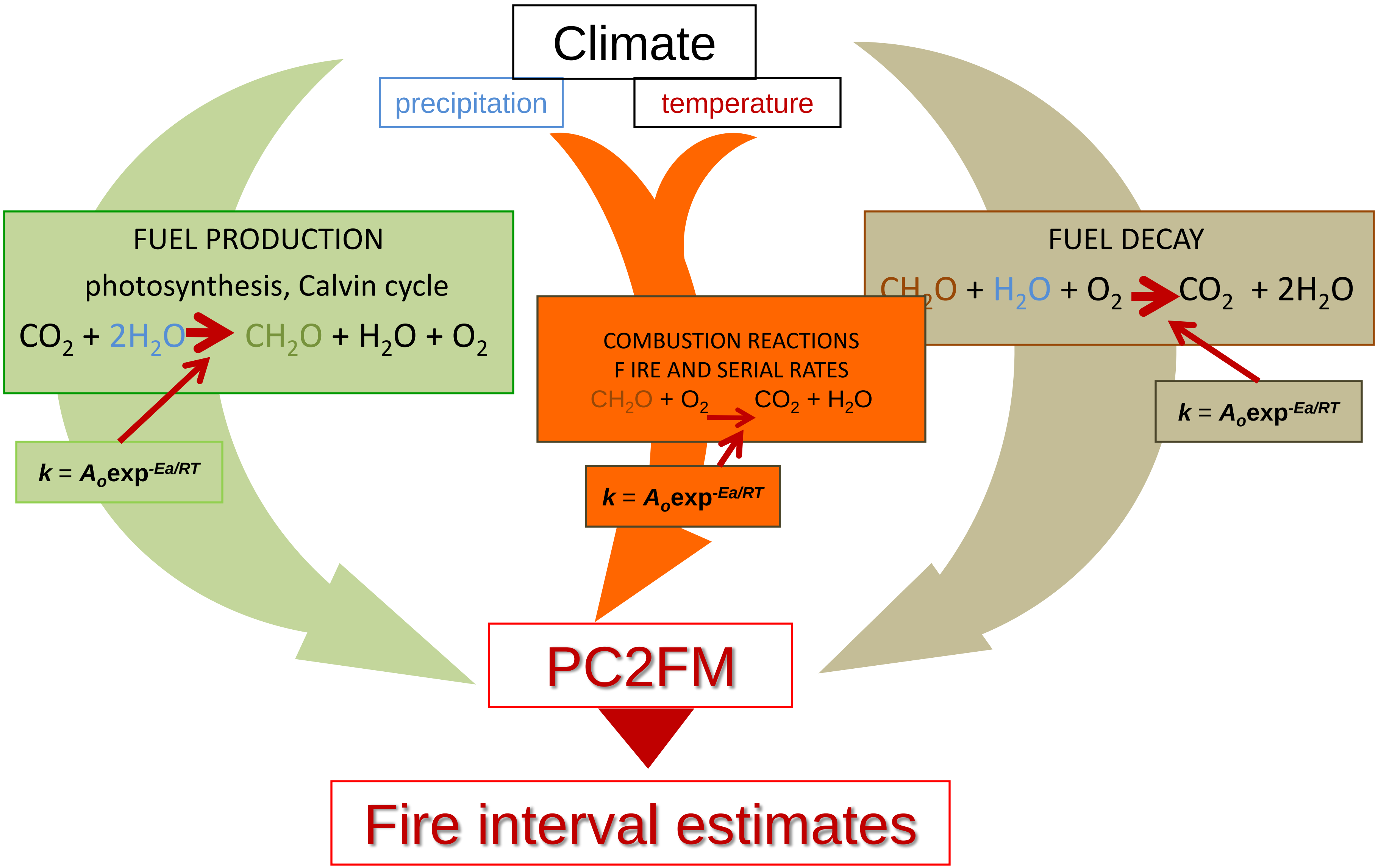
exp = 2.718

E_a = activation energy (kJ per mol)

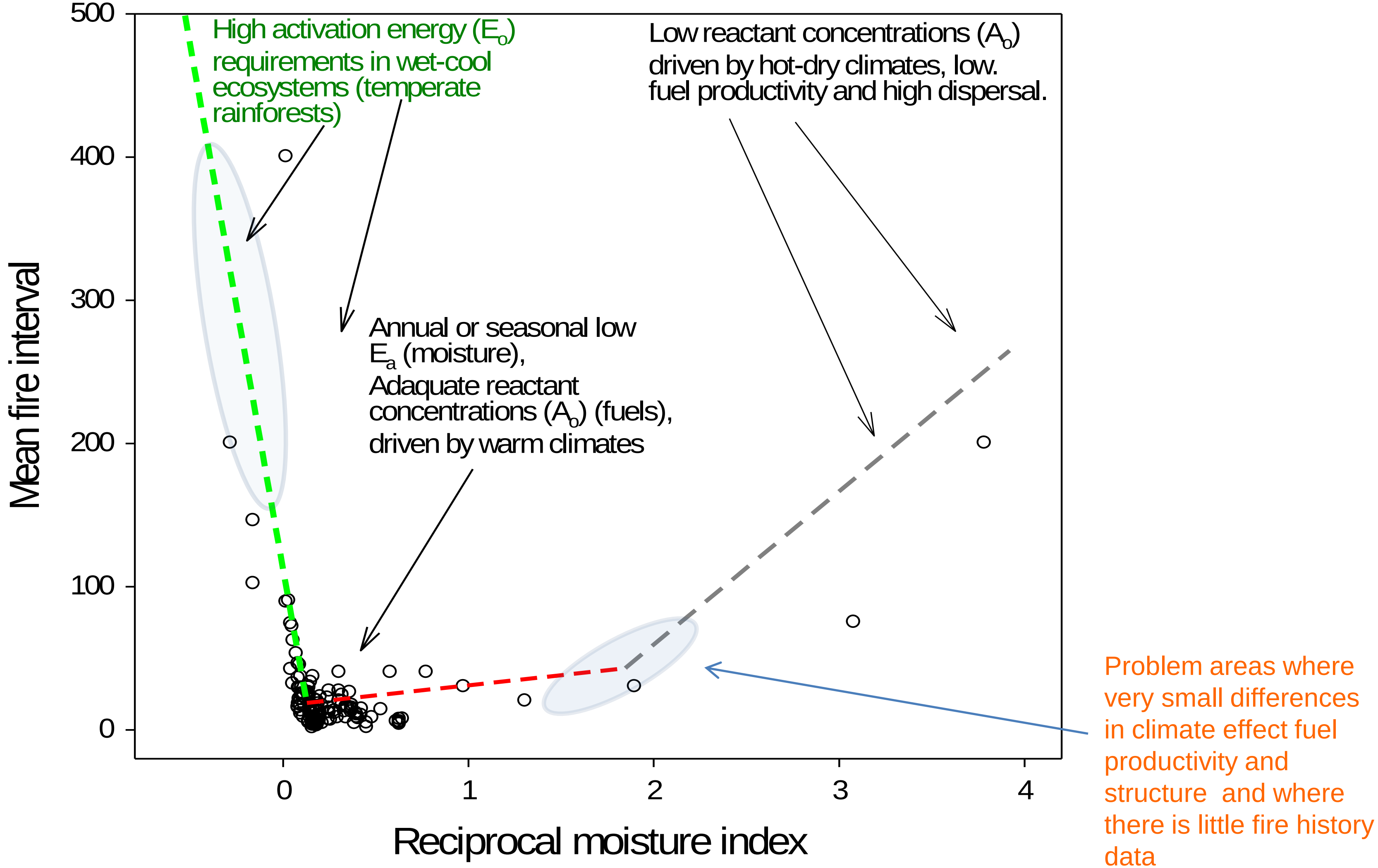
R = gas constant (0.008314 J K^{-1} mol^{-1})

T_{max} = mean maximum temperature in ºK

Both *biological* and *fire* chemistry are *embedded* in the PC2FM equation thru the effects of climate on the reaction rates of fuel production, fuel decay, combustion, and other processes



Parts of the activation energy and the collision frequency terms of the Arrhenius equation are fuel moisture (Ea) and concentration (Ao) and are parameterized by the *reciprocal moisture index,* **1/(*precip/maxt*)**



The PC2FM (Physical Chemistry Fire Frequency Model),

a mechanistic based model for predicting mean fire intervals

The process or mechanistic formulation for prediction:

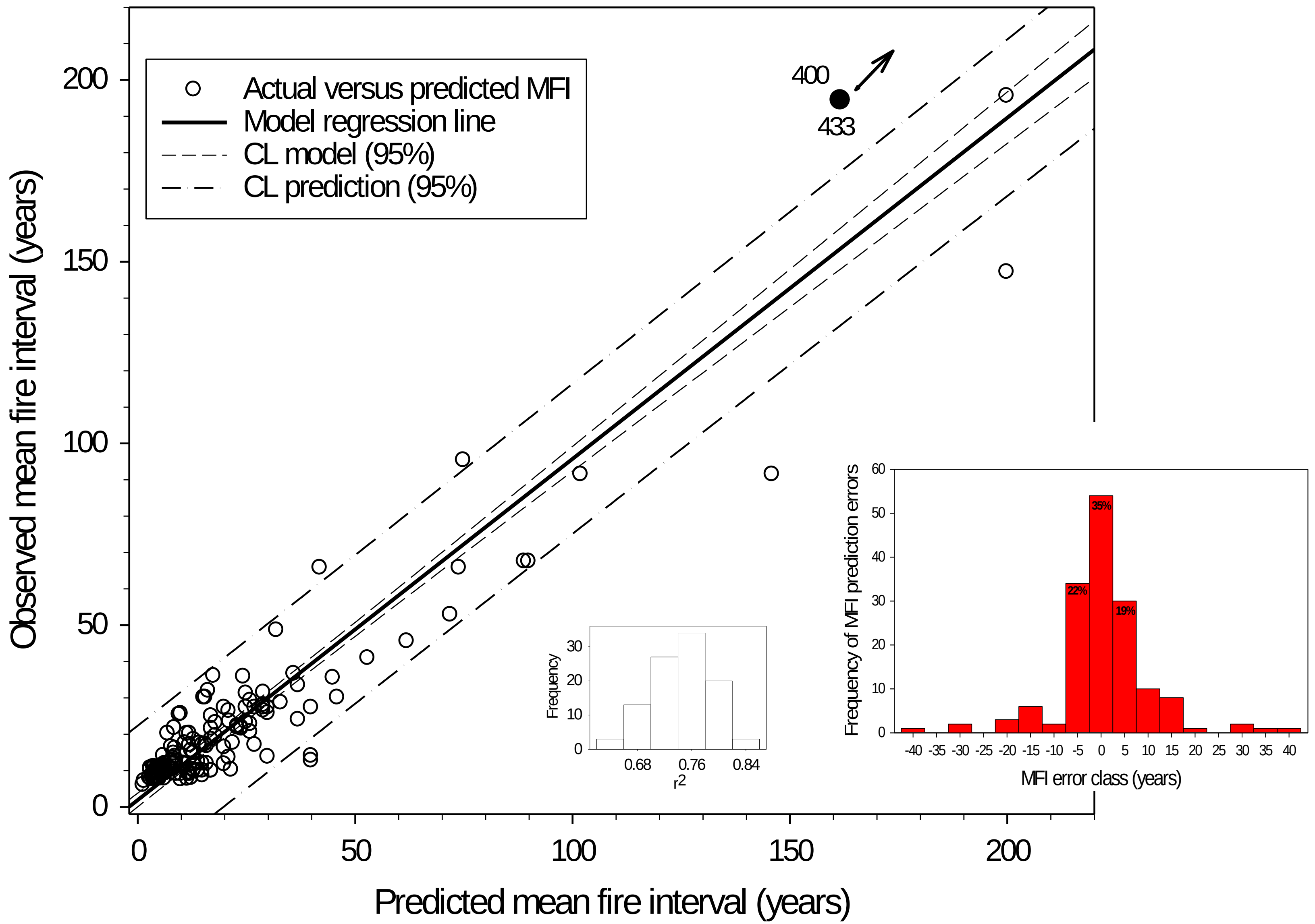
$$\mathbf{MFI = C*exp}^{(-(b1*\mathit{maxt}) + (b2*\mathrm{moisti}) - (b3*\mathit{pop}) + (b4*\mathit{precip}))}$$

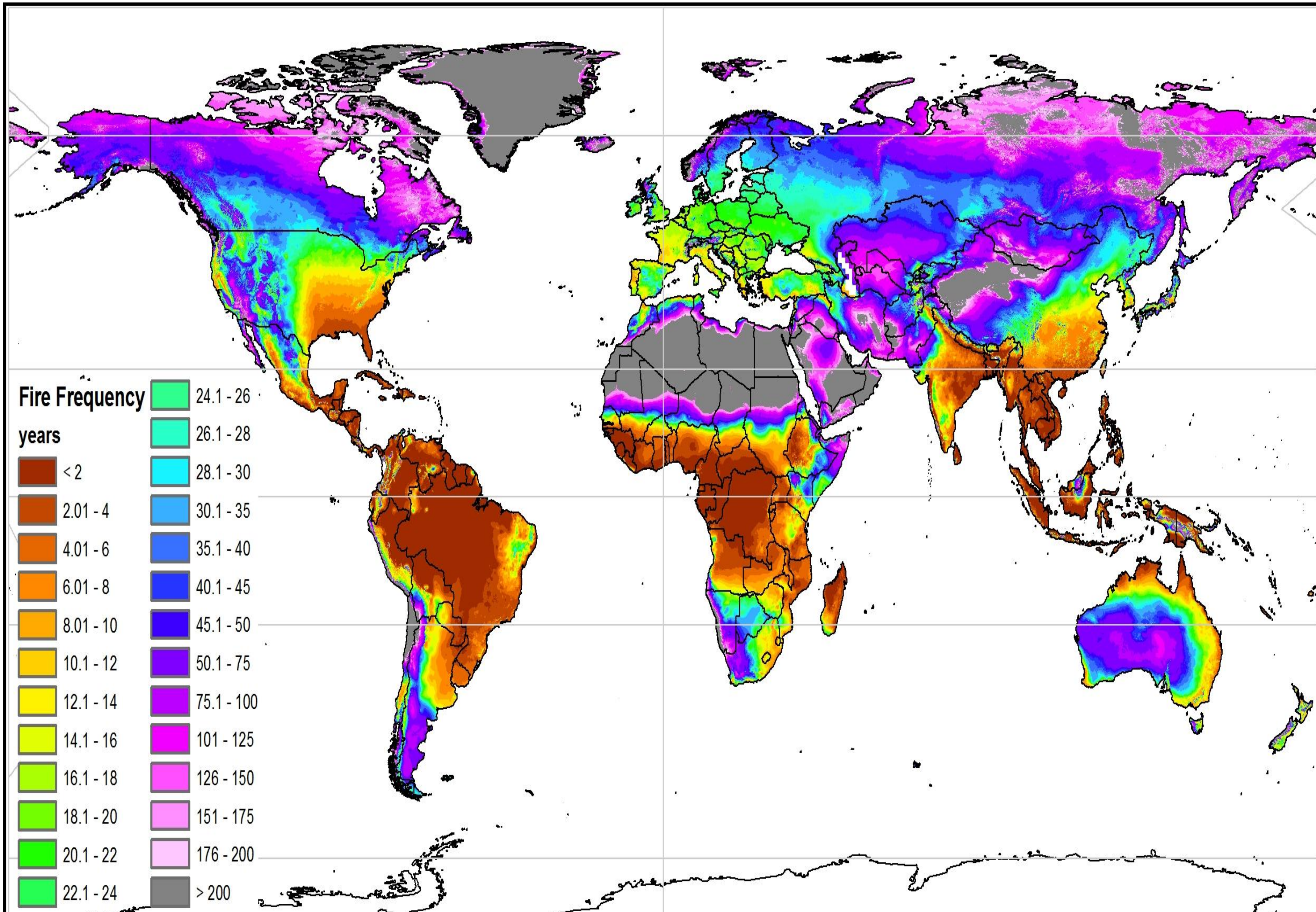
where: **MFI** is the mean fire interval (years),
C is a constant (59.12) derived from the intercept,
exp is 2.718,
maxt is average maximum temperature (^{o}C), partial $\mathbf{r^2}$ = 0.30
moisti the reciprocal of a moisture index 1/(***precip/maxt***), partial $\mathbf{r^2}$ = 0.23
pop is human population density (humans per km^2), partial $\mathbf{r^2}$ = 0.12
precip is mean annual precipitation (cm), partial $\mathbf{r^2}$ = 0.10
model $\mathbf{r^2}$ = 0.75, (tested)
period of calibration:~1650 and 1850 AD.
number fire history sites, model = 78, tested on 155 with replacement.

The deterministic model formulation for dependent variable normality and statistical validation:

$$\mathbf{ln(MFI)} = 4.08 - (0.139*\mathit{maxt}) + (1.50*\mathbf{moisti}) - (2.41*\mathit{pop}) + (0.00763*\mathit{precip})$$

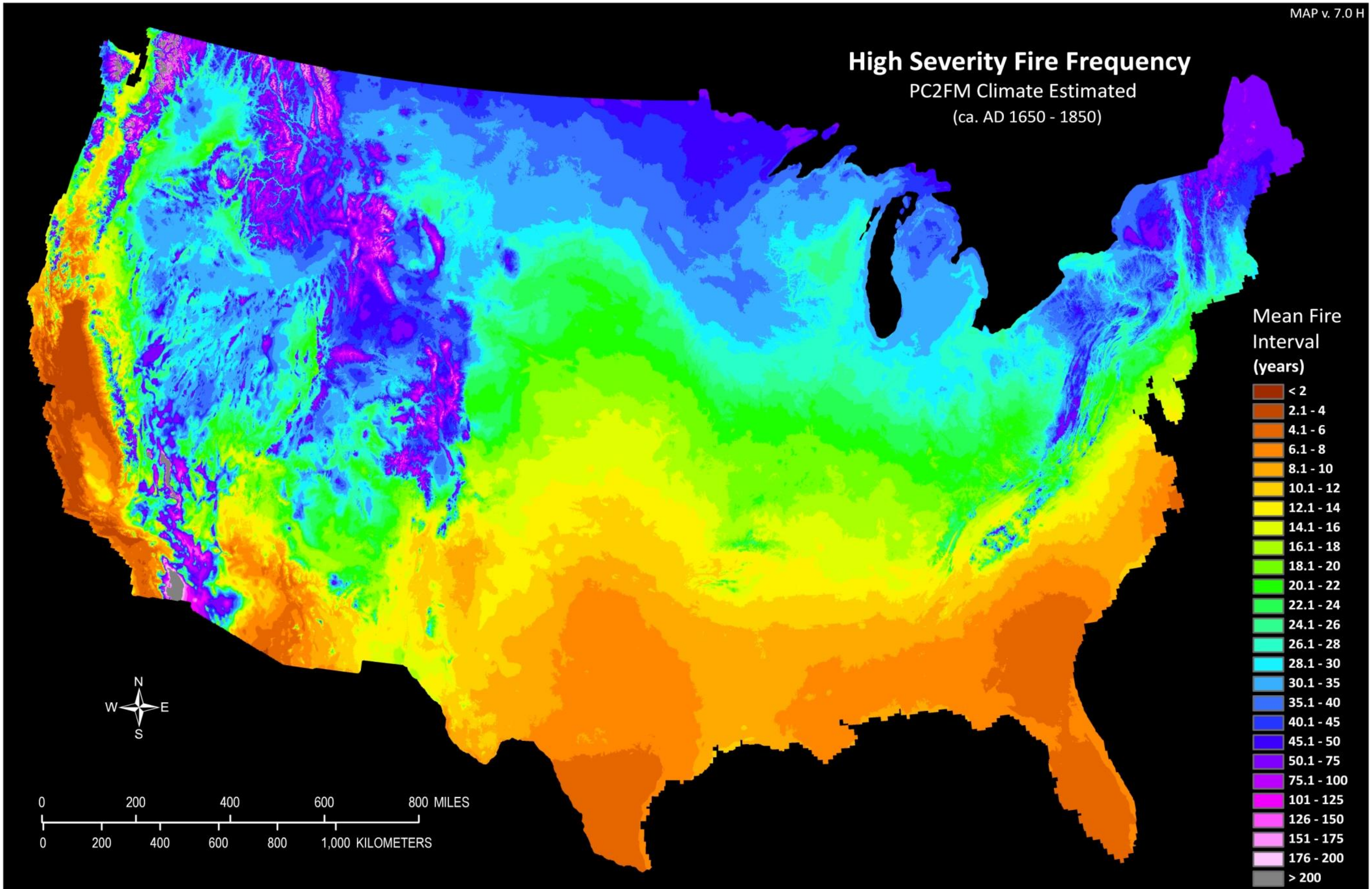
Observed versus predicted MFI




Fire Frequency
years
< 2
2.01 - 4
4.01 - 6
6.01 - 8
8.01 - 10
10.1 - 12
12.1 - 14
14.1 - 16
16.1 - 18
18.1 - 20
20.1 - 22
22.1 - 24
24.1 - 26
26.1 - 28
28.1 - 30
30.1 - 35
35.1 - 40
40.1 - 45
45.1 - 50
50.1 - 75
75.1 - 100
101 - 125
126 - 150
151 - 175
176 - 200
> 200

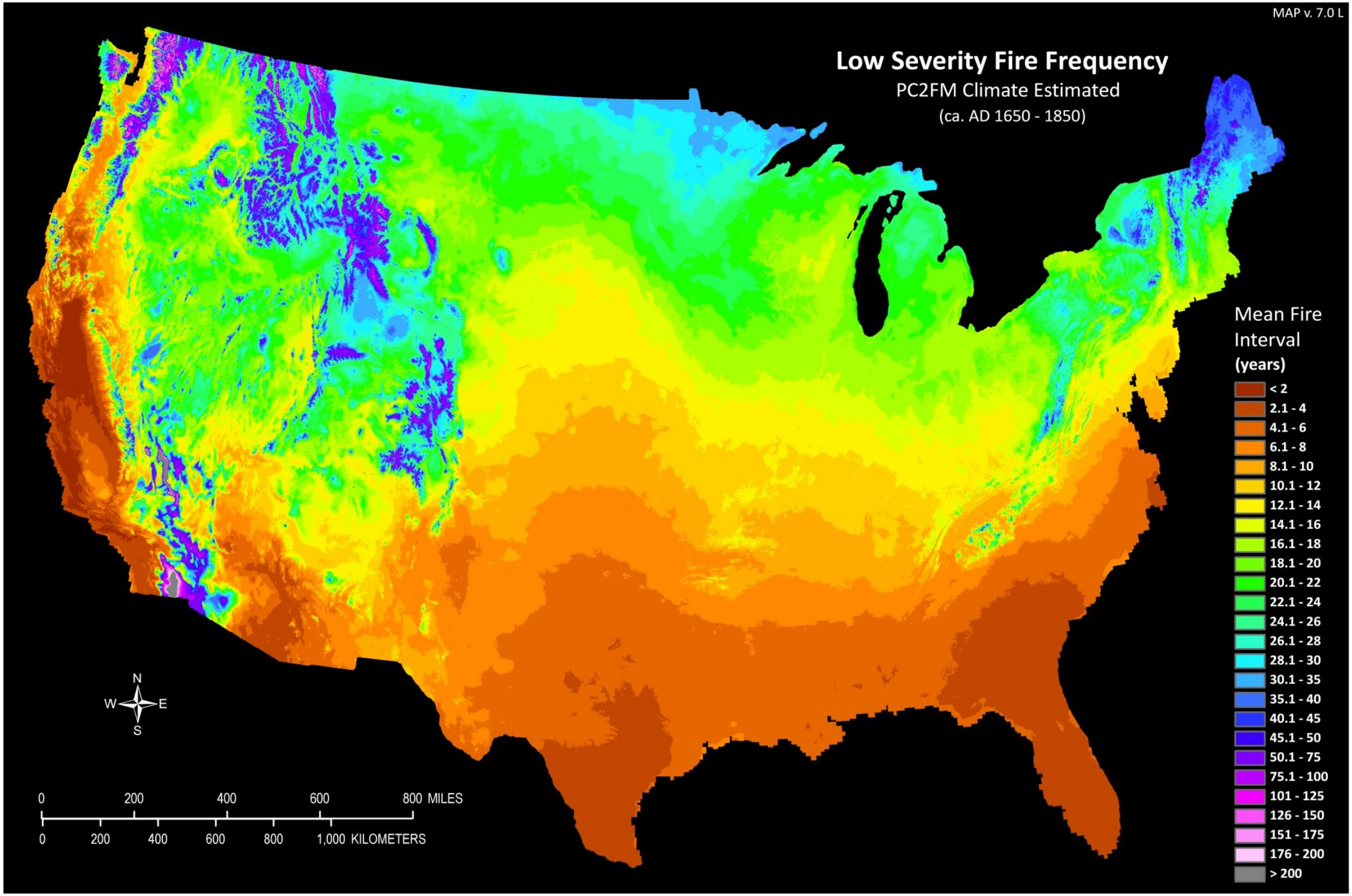
High severity frequency based on a 1 to 6 average ratio of fire history site data

MFI = C*exp$^{(- 0.139*maxt + 1.50*moisti - 2.41*pop + 0.00763*precip}$, *where C = 108..2*



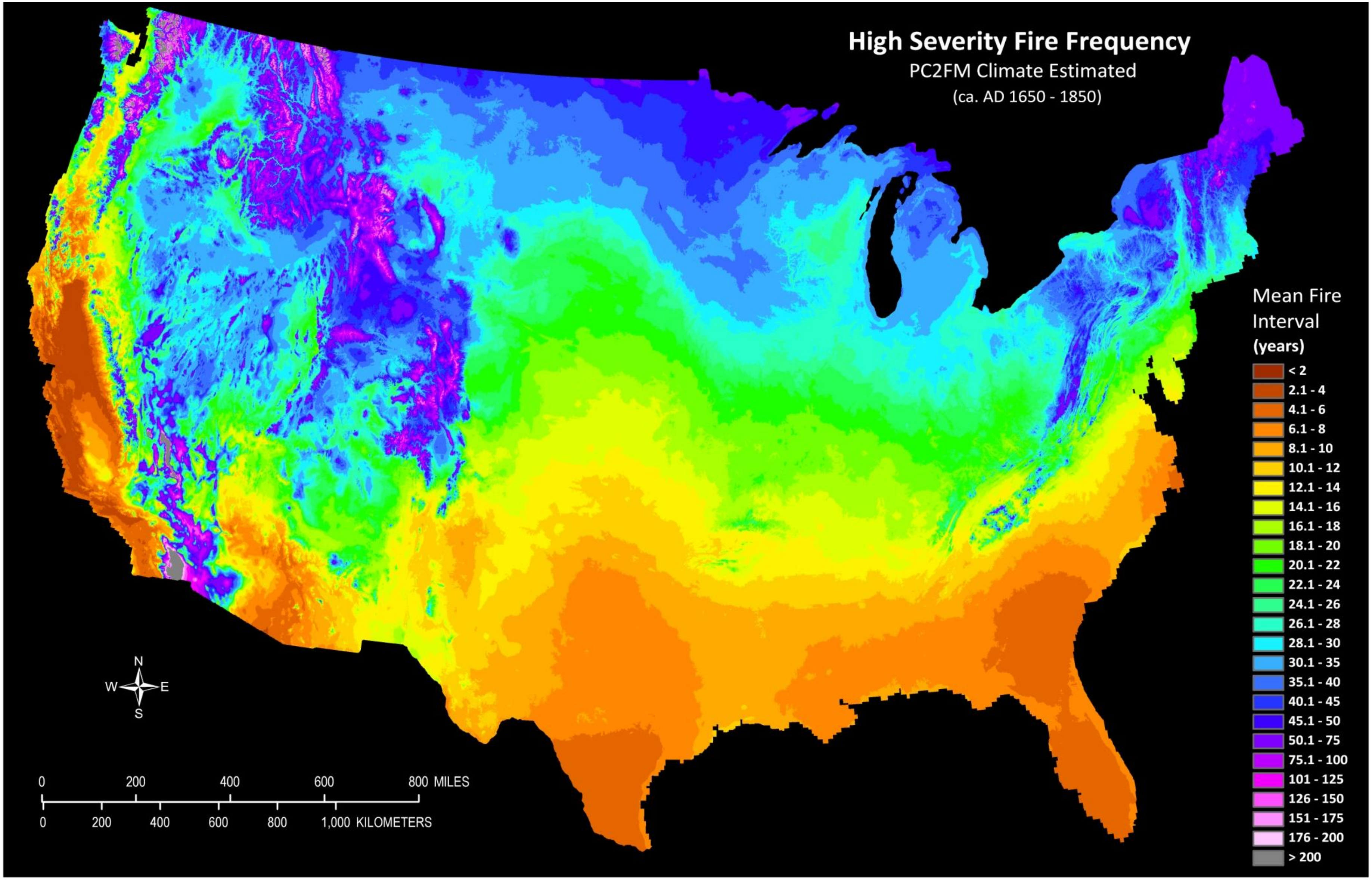
Low severity frequency based on a 6 to 1 average ratio of fire history site data

$$MFI = C * \exp^{(-0.139*\mathit{maxt} + 1.50*\mathrm{moisti} - 2.41*\mathit{pop} + 0.00763*\mathit{precip},} \quad \textit{where } C = 69.2$$



Fire frequency is driven at very broad scales by geologic and planetary effects

1. Latitudinal-temperature driven MFIs are probably ***global*** in extent like these on the Great Plains
2. Elevational-temperature and precipitation driven MFIs are probably ***global*** in extent like these in the West
3. Ocean circulation effects on terrestrial temperature, precipitation, and MFIs are a ***global*** in extent



Since we have:

1. Identified important climate-fire variables
2. Calibrated and validated these variables
3. Modeled over a wide range of climates that closely mirror global means

We can:

1. Use the PC2FM to examine global climate forcing of fire regimes
2. Identify the limitations and potentials of this approach

PC2FMs with population removed and mean temperature for global assessments

Low severity fires

$$\mathbf{MFI_{ls} = 27.5exp^{-(0.178*\mathit{mtemp}) + (2.3*\mathit{moisti})+(0.00765*\mathit{precip})}}$$

High severity fires

$$\mathbf{MFI_{hs} = 43.2exp^{-(0.178*\mathit{mtemp}) + (2.3*\mathit{moisti})+(0.00765*\mathit{precip})}}$$

where: **MFI** is the mean fire interval (years),
exp is 2.718,
mtemp is mean temperature (^{o}C),
moisti the reciprocal of a moisture index 1/***(precip/mtemp***),
pop is human population density (humans per km^2),
precip is mean annual precipitation (cm),
period of calibration:~1650 and 1850 AD.

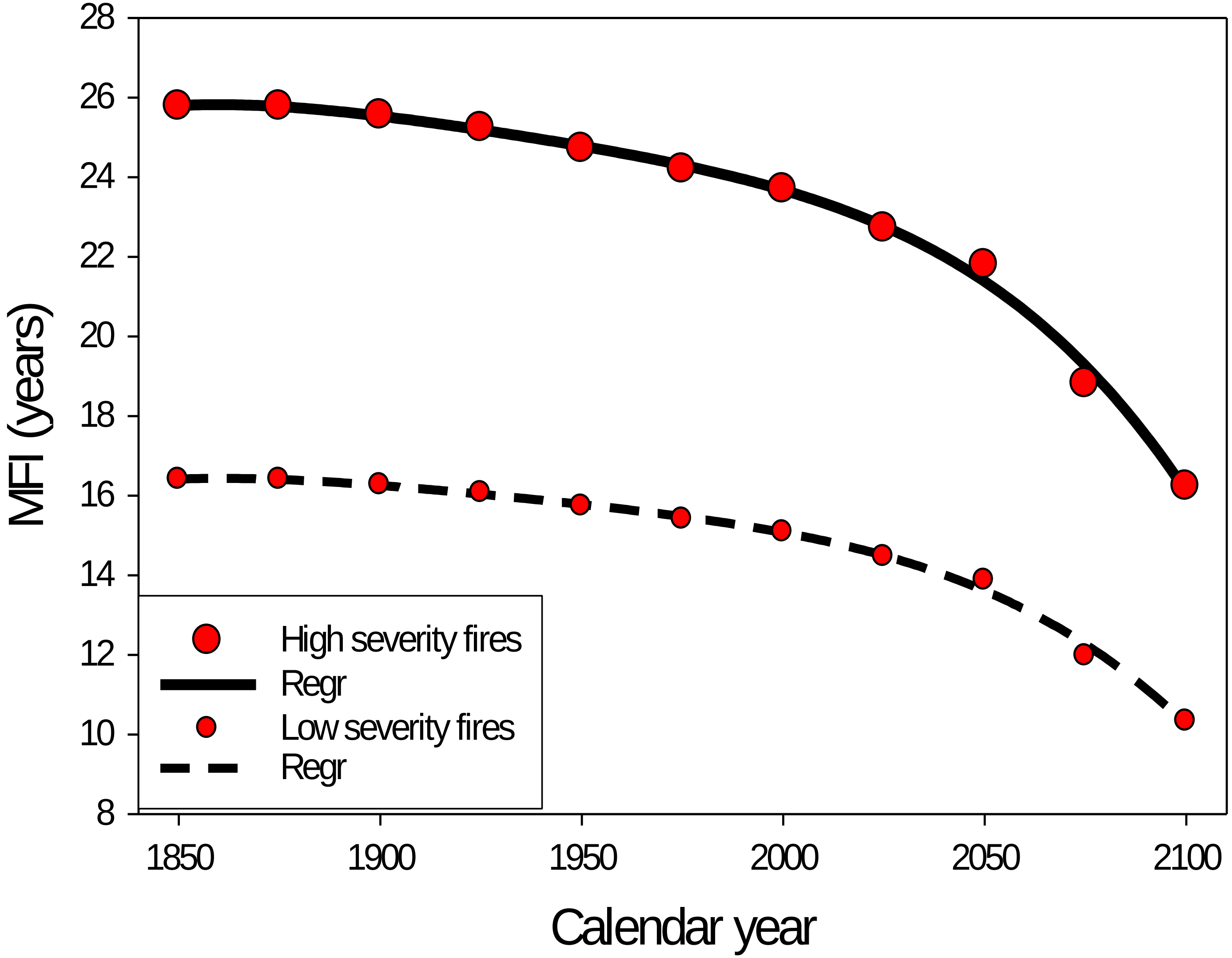
Definitions and limitations

PC2FM scenarios are not yet spatially explicit, but do use ***global terrestrial climate*** estimates (excluding Antarctica)

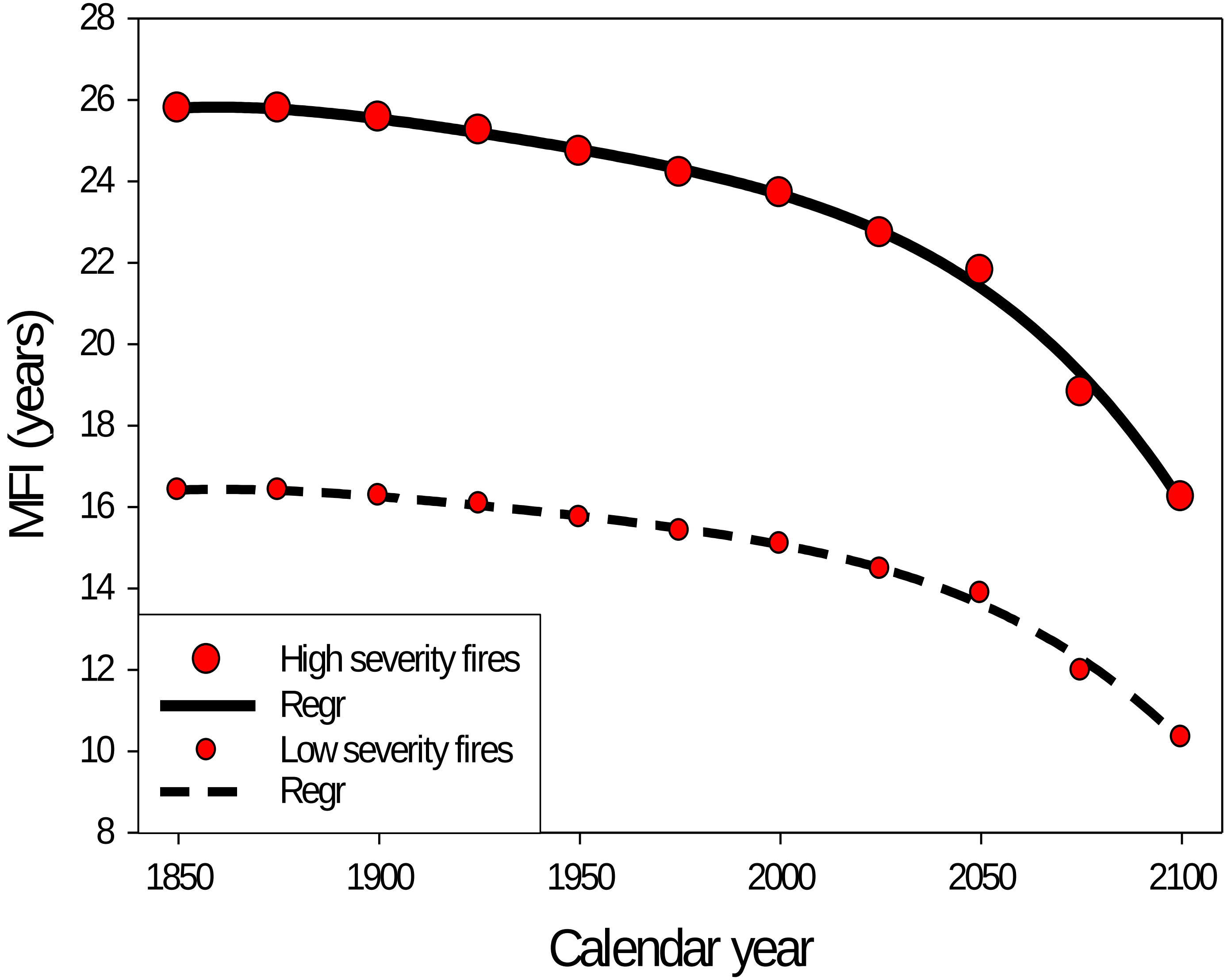
Predicted mean fire intervals (MFI) here are reaction rates based ***only on the physical chemistry and climate*** of ecosystems

Predicted climate forced mean fire intervals (MFI) ***do not include many other factors*** that can control fire frequency such as fire suppression, prescriptions, human fuel treatments, and population density (in the $PC2FM_{np}$)

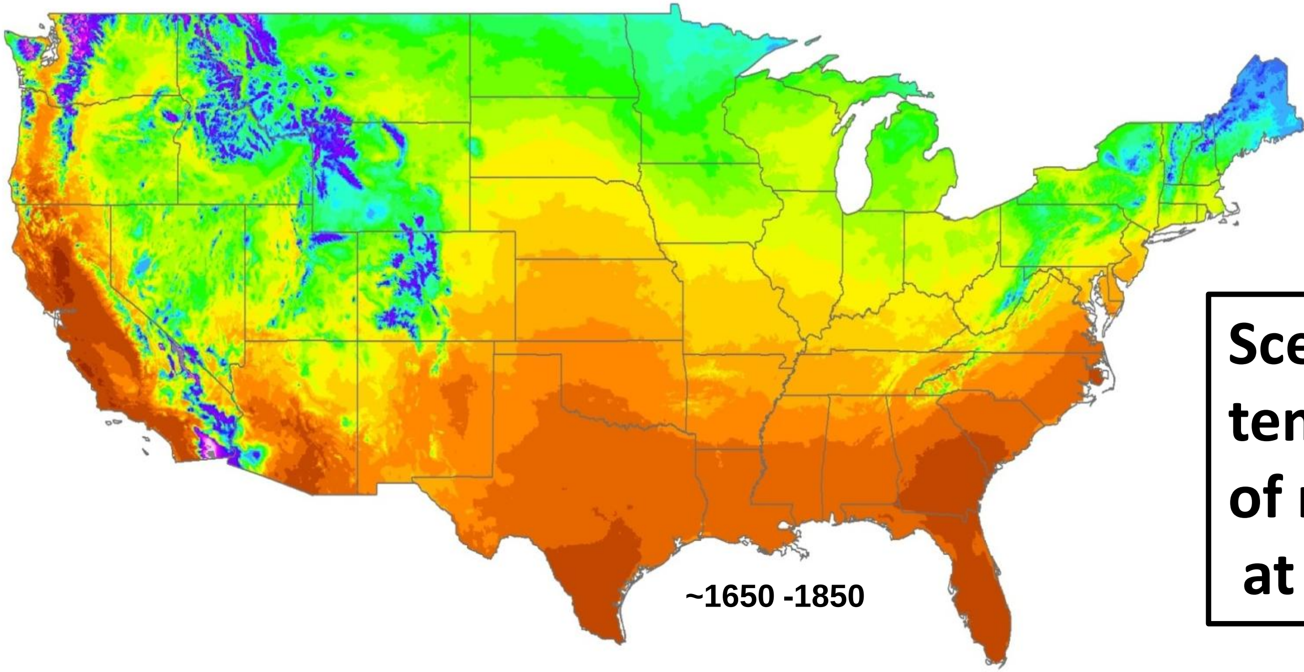
PC2FM results for climate forcing of future fire frequency based on temperature increases predicted by 'business as usual' temperature scenario

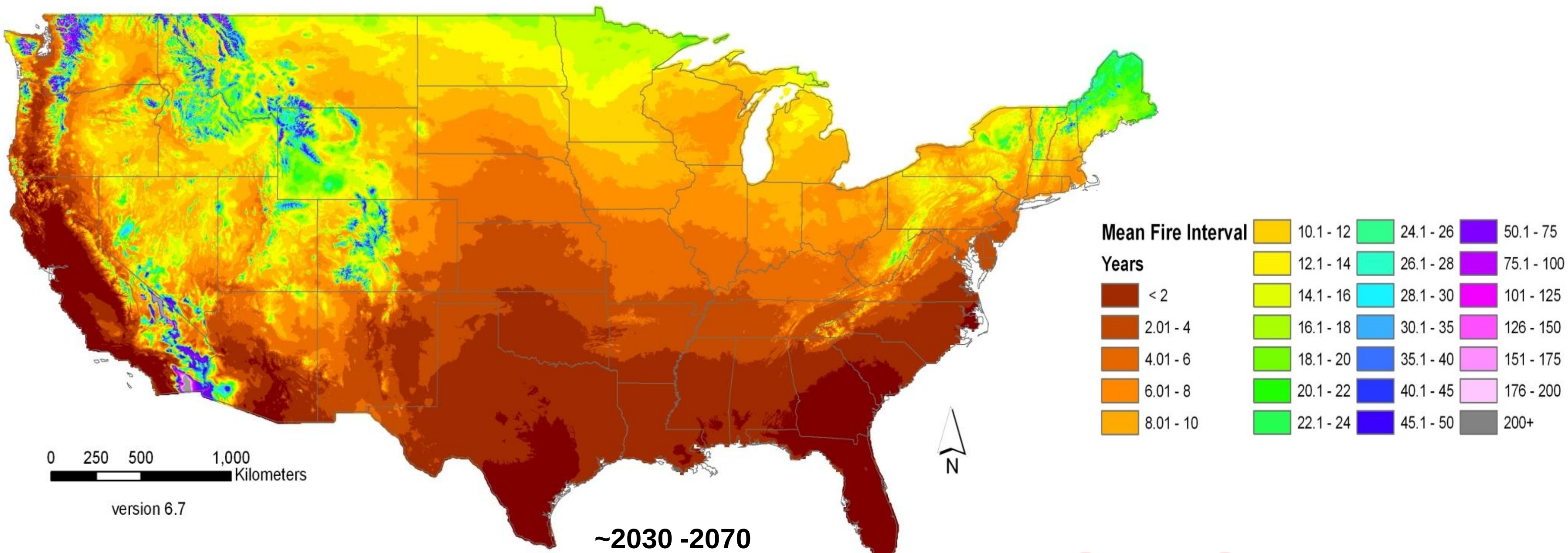


This will result in a 37% increase in the climate forcing of future fire frequency based on temperature alone as predicted by 'business as usual' temperature scenario



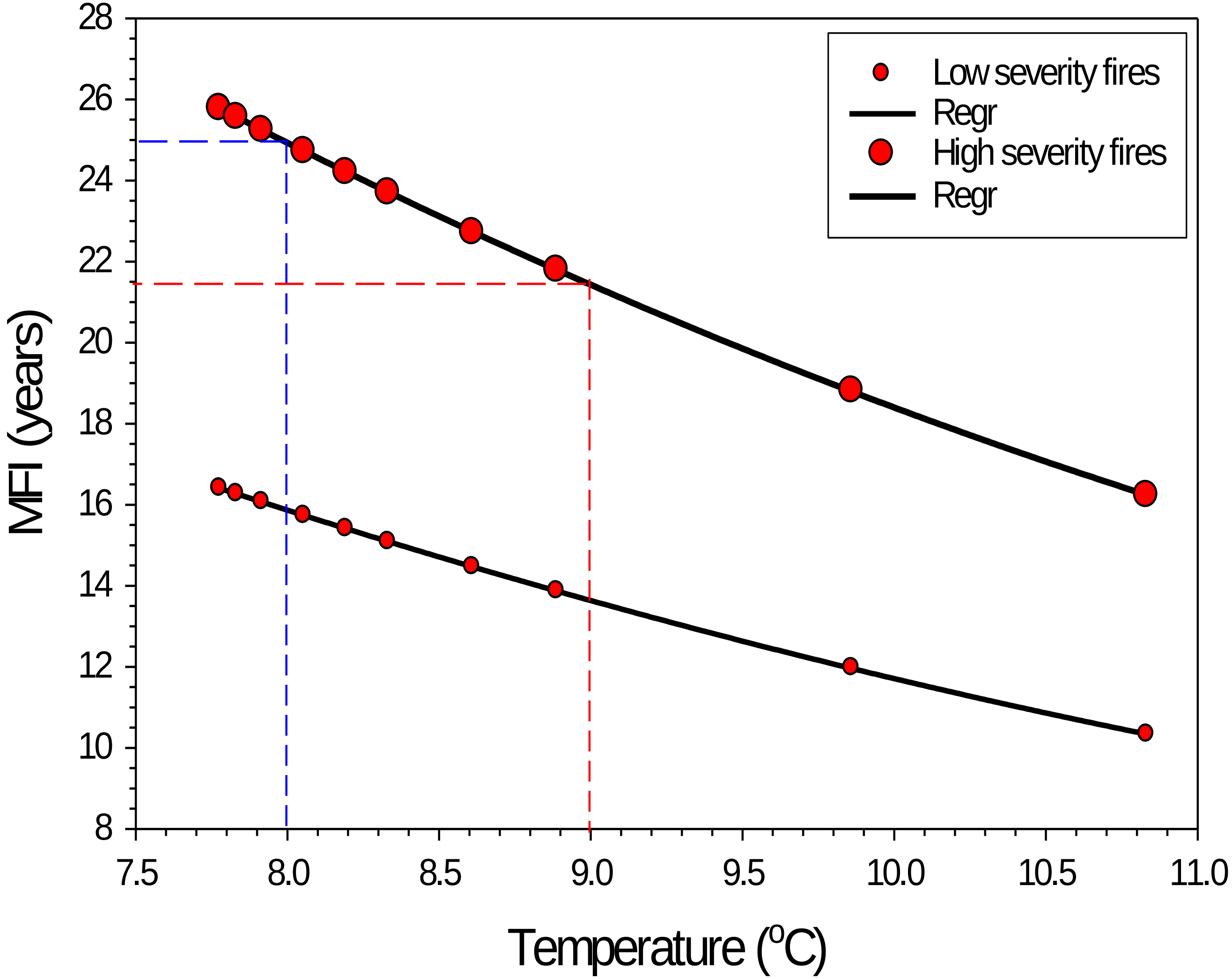
Scenario 1: Potential temperature forcing of mean fire intervals at +3 °C.



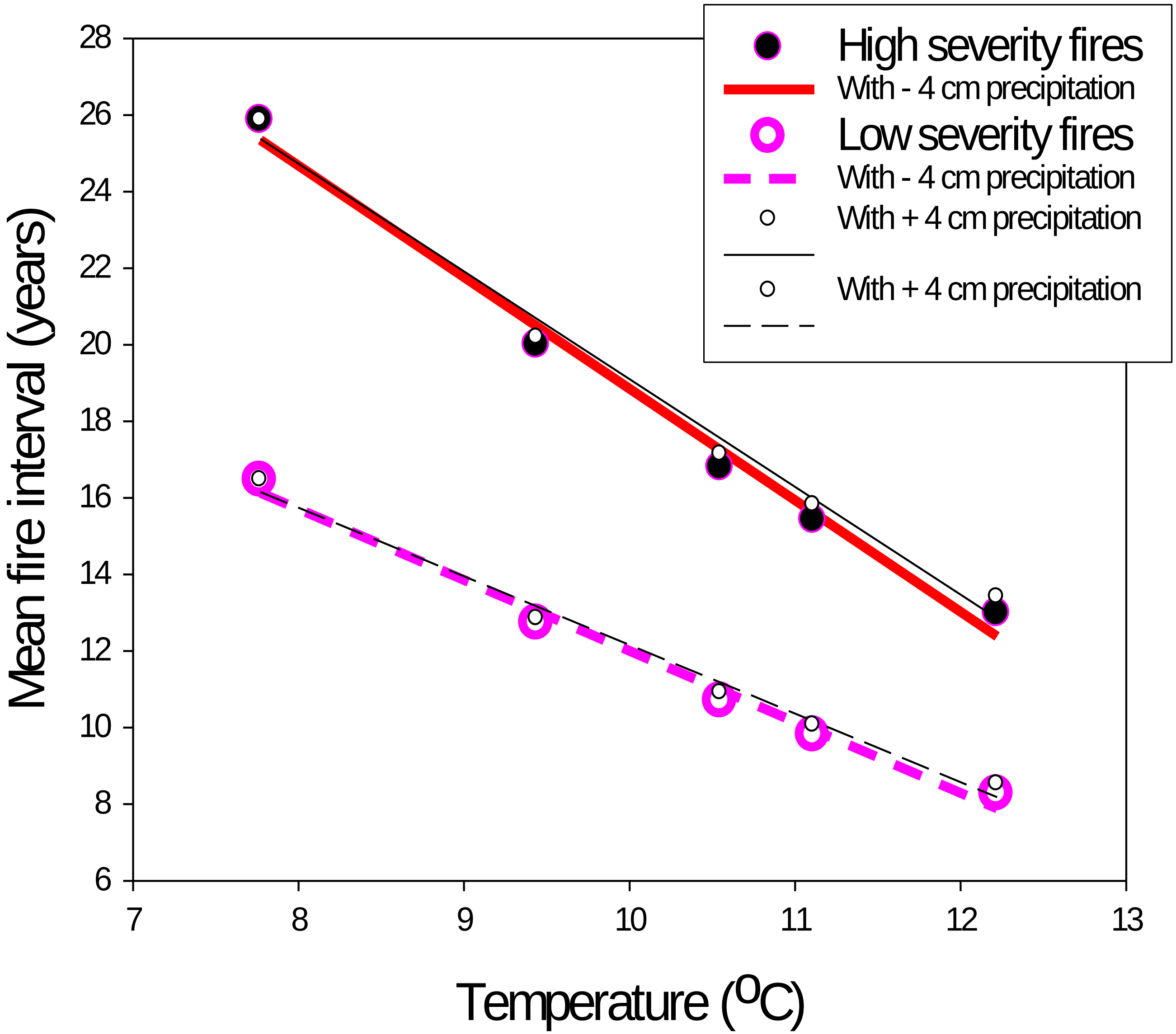


MFI = C*exp(- 0.139*$maxt$ + 1.50*moisti - 2.41*pop + 0.00763*$precip$)

A 3.5 year (14 %) decrease in the mean fire interval for every 1 °C increase in temperature is predicted for severe fires by the PC2FM non-linear regression at this inflection point

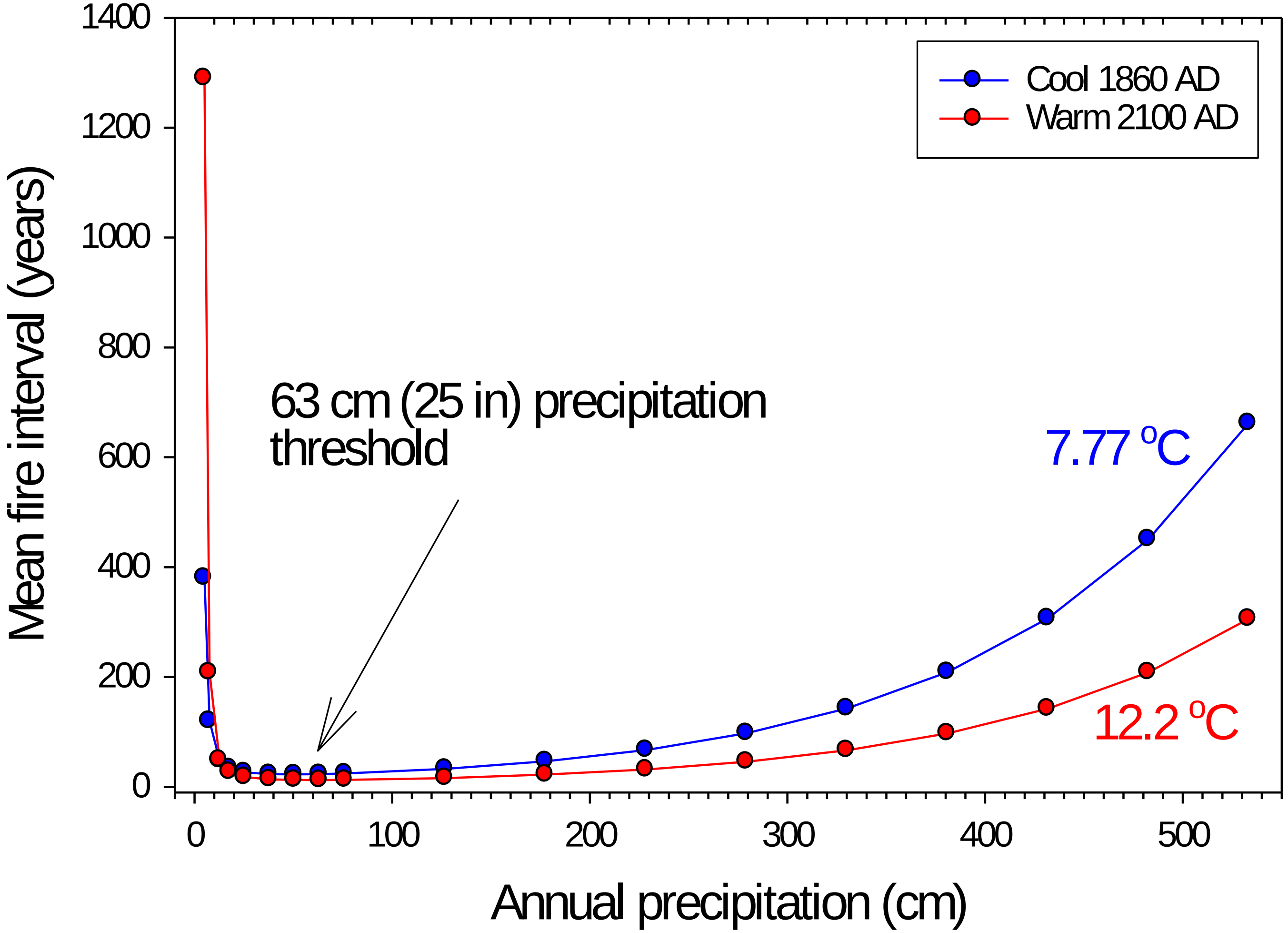


Climate forcing of fire intervals based on $PC2FM_{np}$ model scenarios of temperature and precipitation

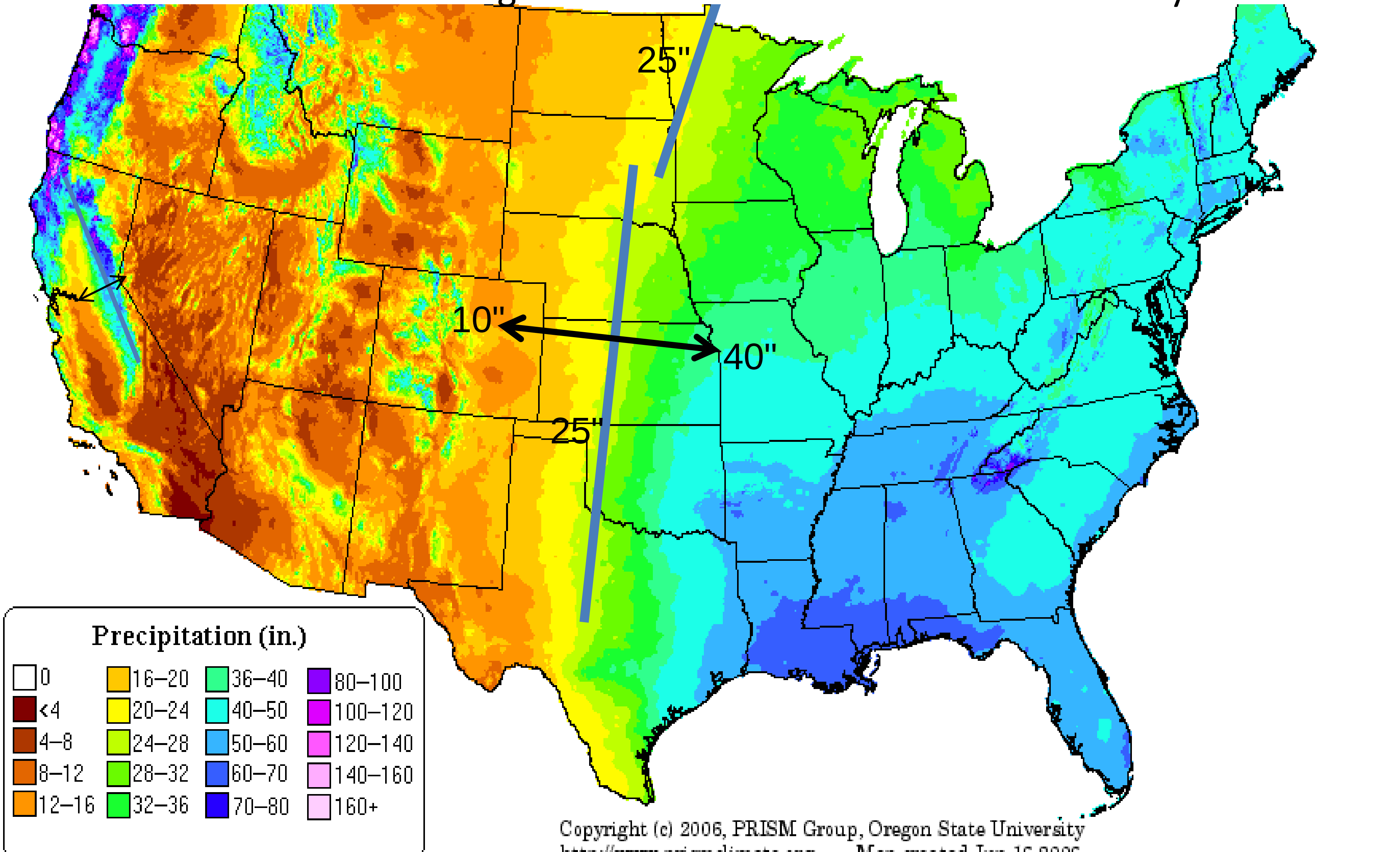


below 63 cm: > precipitation > fire frequency

above 63 cm: > precipitation < fire frequency

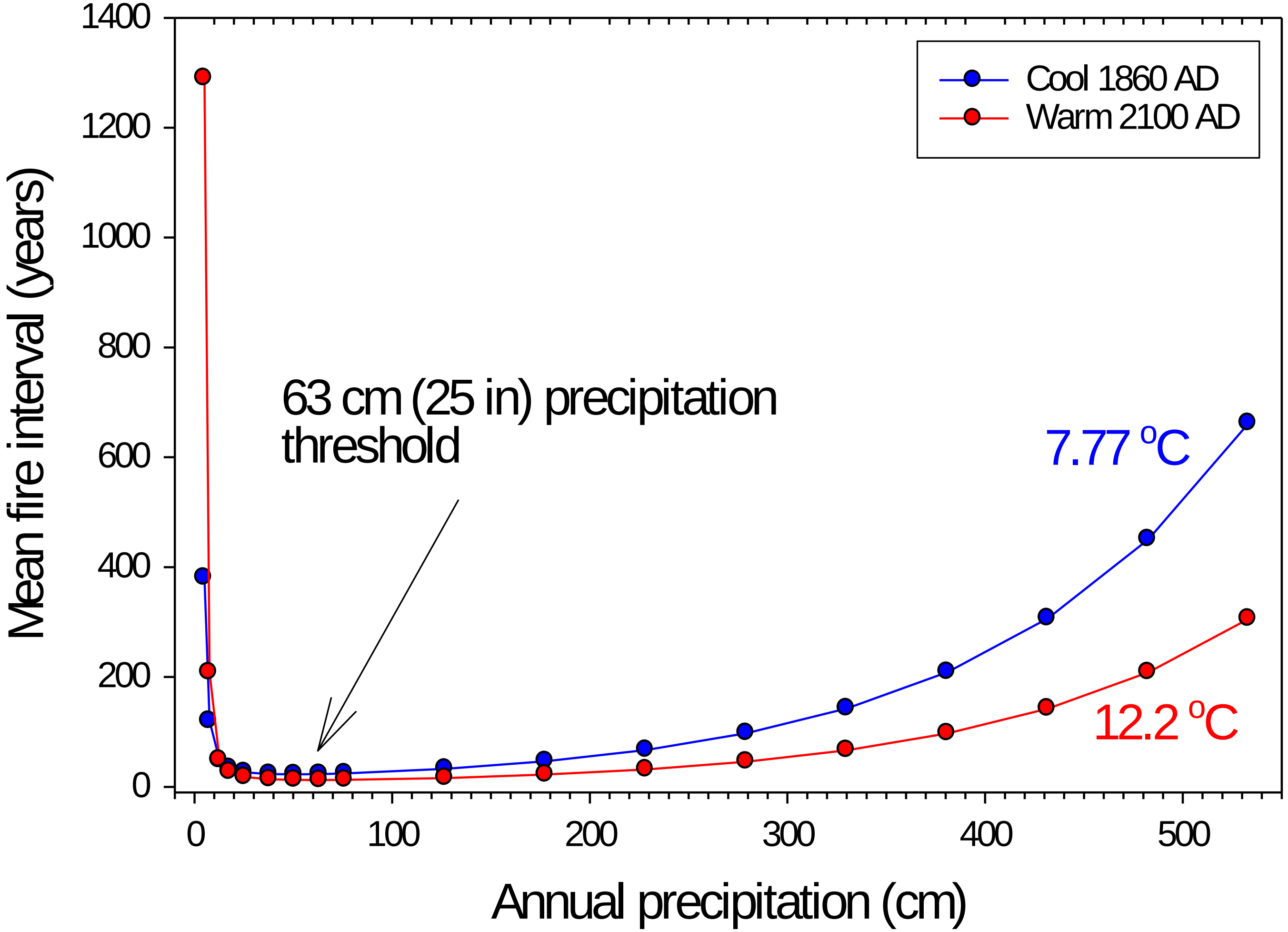


The blue lines follow the 25 inches (63 cm) precipitation threshold for the positive versus the negative effects of precipitation on fire frequency. East to west in the Great Plains there is a 30 inch difference in rainfall. An elevation caused precipitation gradient and threshold lies along the eastern border of the Central Valley in California.

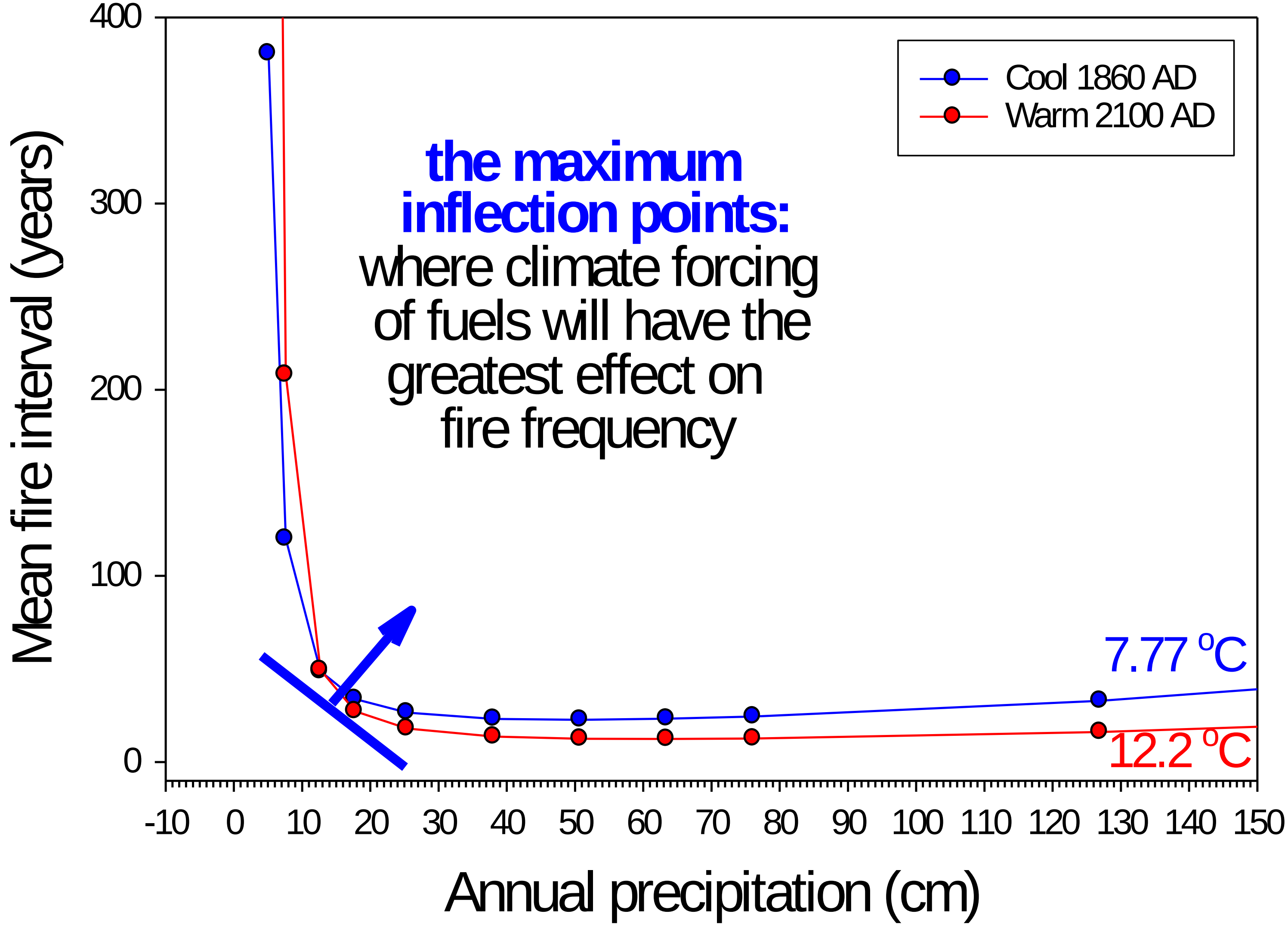


below 63 cm: > precipitation > fuels (A_o)

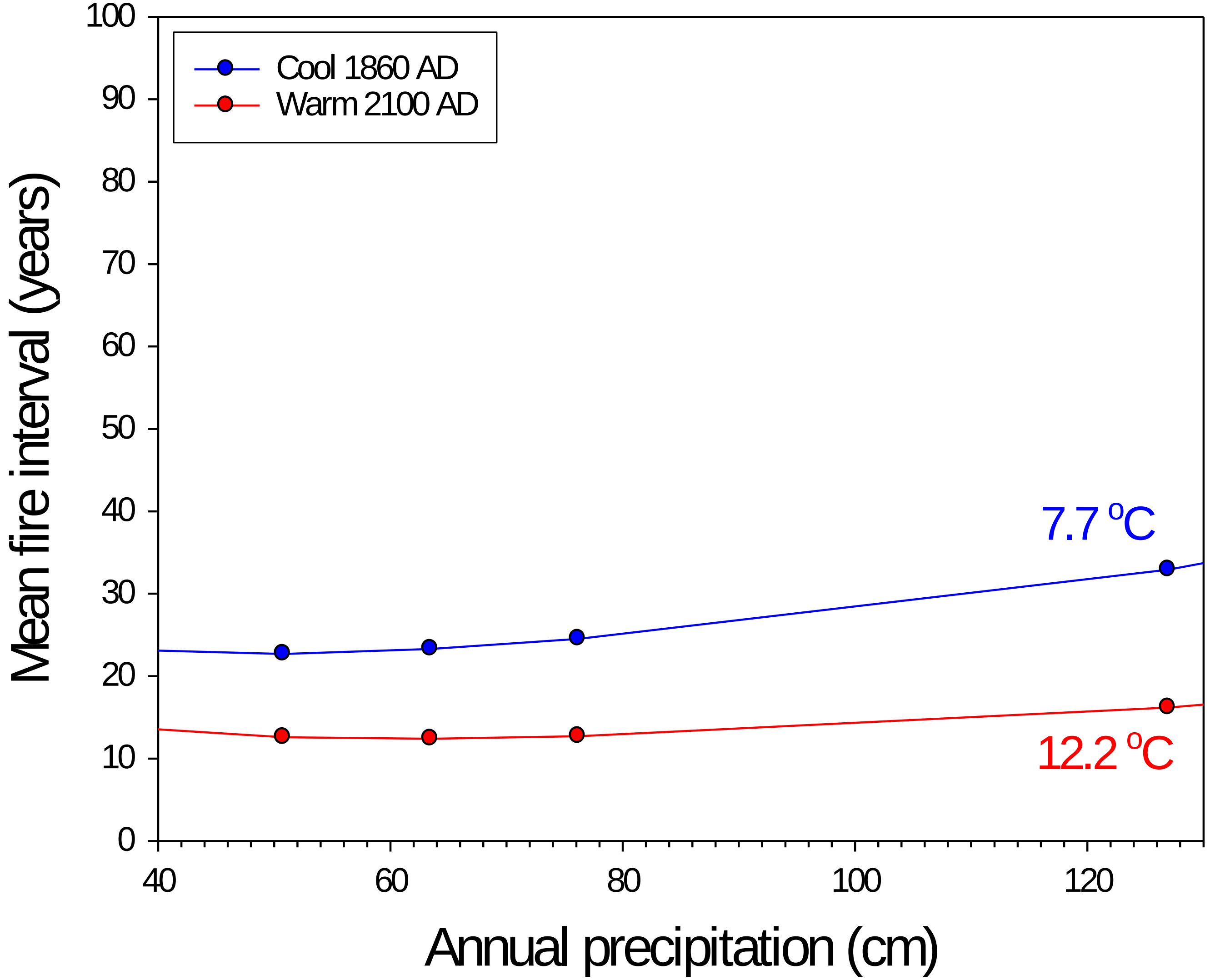
above 63 cm: > precipitation > fuel moisture (E_a)



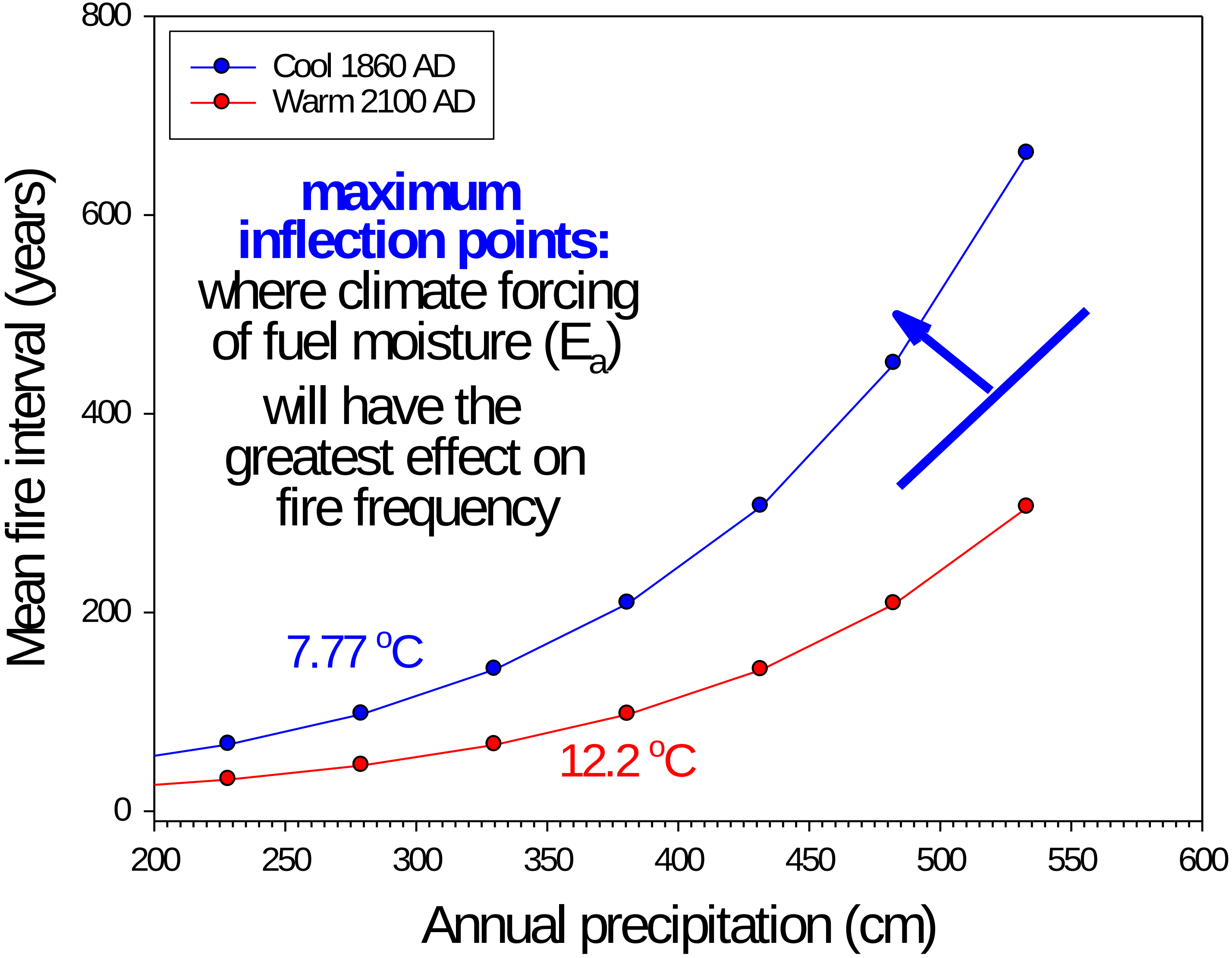
Climate regions with between 15 and 30 cm of precipitation will have the greatest increase in fire frequency with increases in precipitation



Climate regions where the effects of increased precipitation will be small because fuel moisture (E_a) and production (A_o) will balance each other



Climate regions with between 400 and 600 cm of precipitation will have the greatest rate of decrease in fire frequency with increases in precipitation



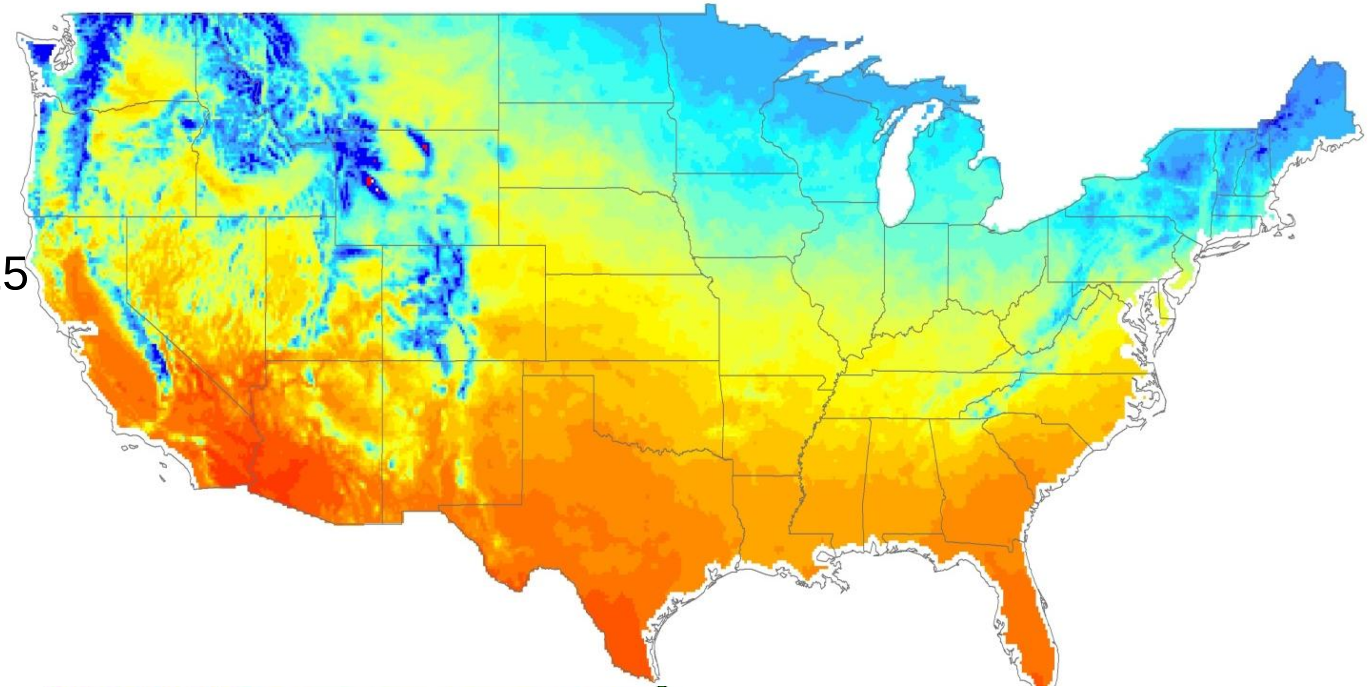
Acknowledgements

- Thanks to the many authors who have made their fire histories and data available through publication, personal contact, the International Mulitproxy Paleofire Data Base, and PRISM Products as well as the support from the many agencies over the years.
- Joint Fire Science Program
- Northern Research Station, USDA Forest Service
- National Park Service
- Missouri Department of Conservation
- Southern Station, USDA Forest Service
- University of Missouri, Department of Forestry
- Arnold Air Force Base
- Ontario Ministry of Natural Resources
- Oklahoma Department of Conservation

12,000 yrs BP

Pre-Holocene fire intervals

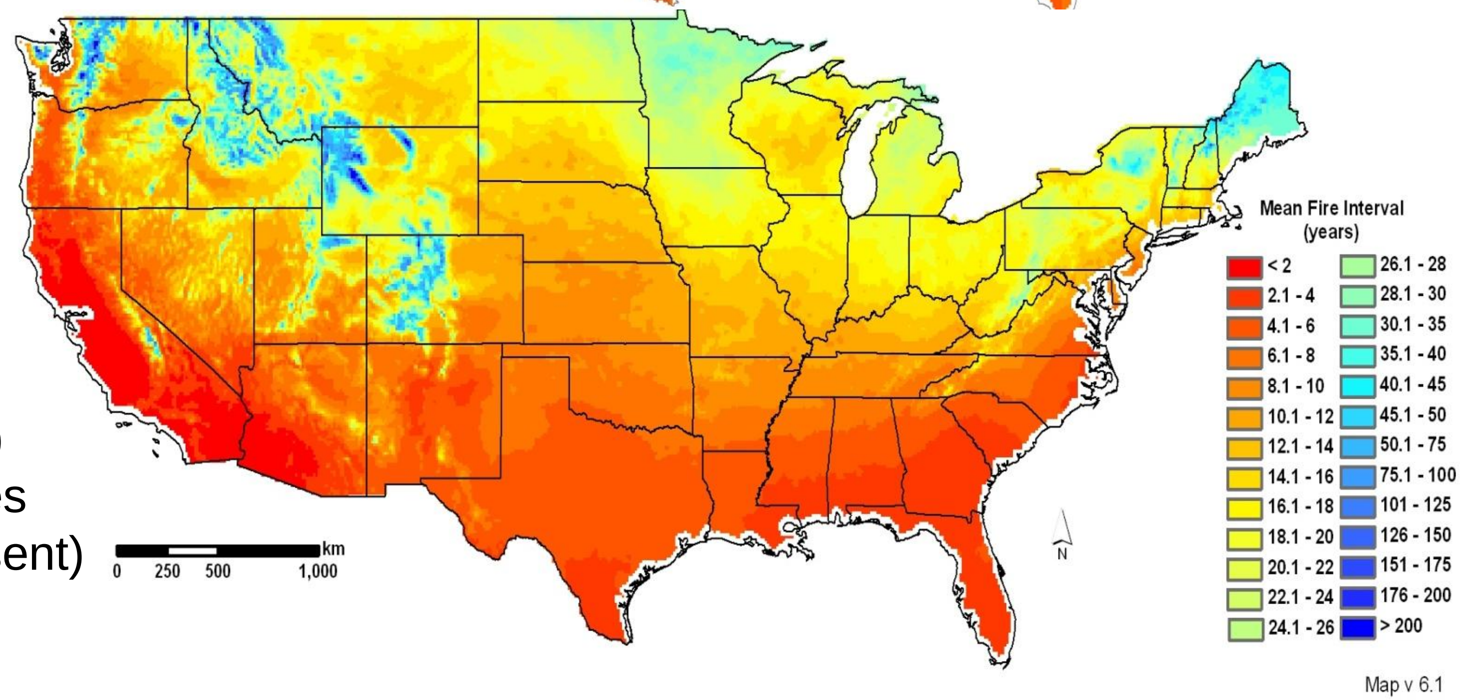
~few humans (< 0.015 humans/km^2)
cooler temperatures
~ (2 °C less than present)



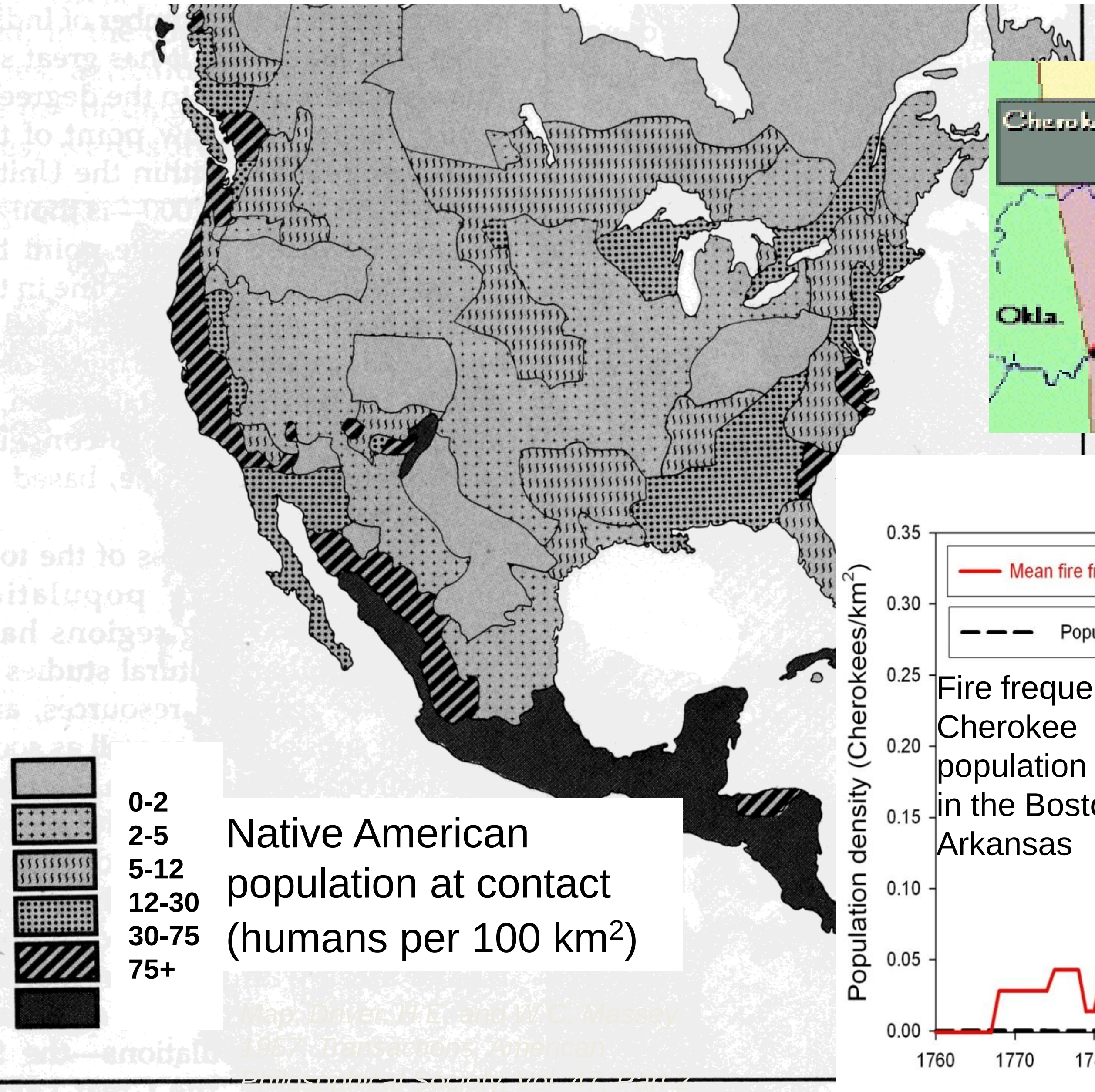
250 yrs BP

Pre-Euro American fire intervals

many humans
~(0.15 humans/km^2)
warmer temperatures
~ (0.4 °C <than present)

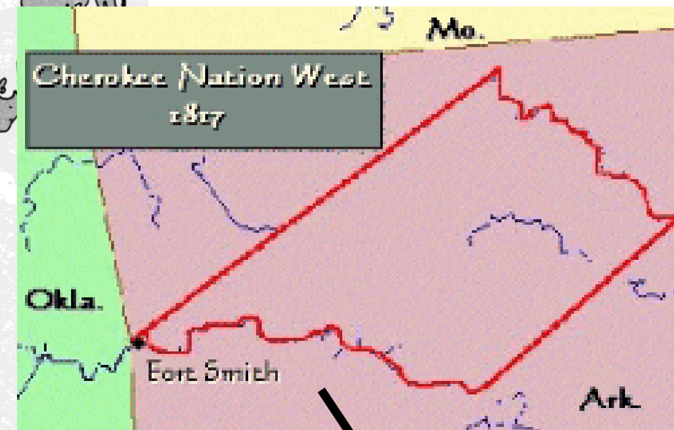


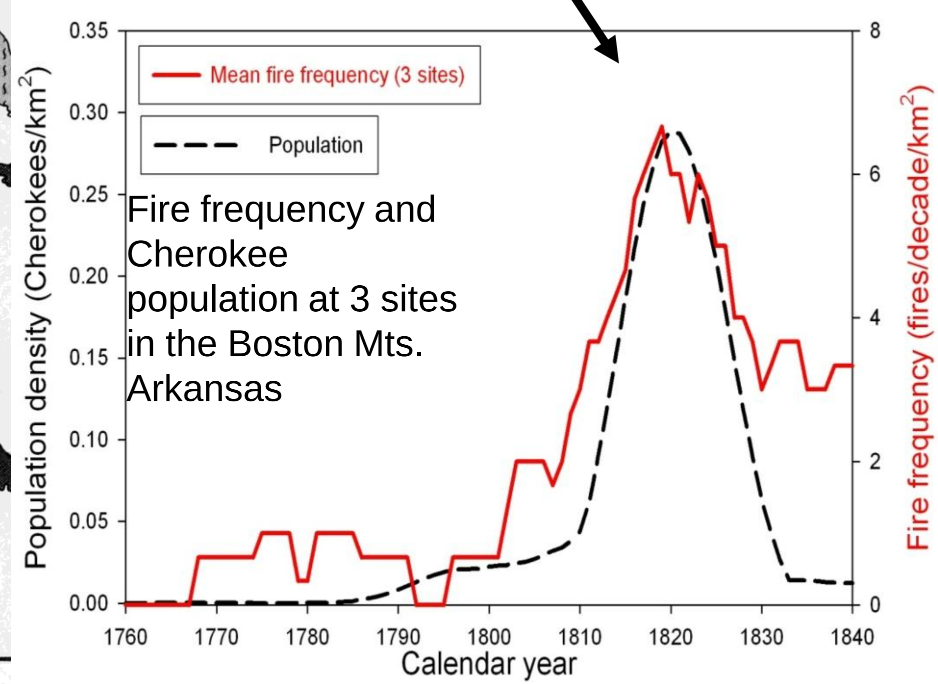
Human population density is an ignition proxy associated with the frequency of wildland fires



Native American population at contact (humans per 100 km²)

Map: Driver, H.E. and W.C. Massey 1957. Transactions, American Philosophical Society, Vol. 47, Part 2.

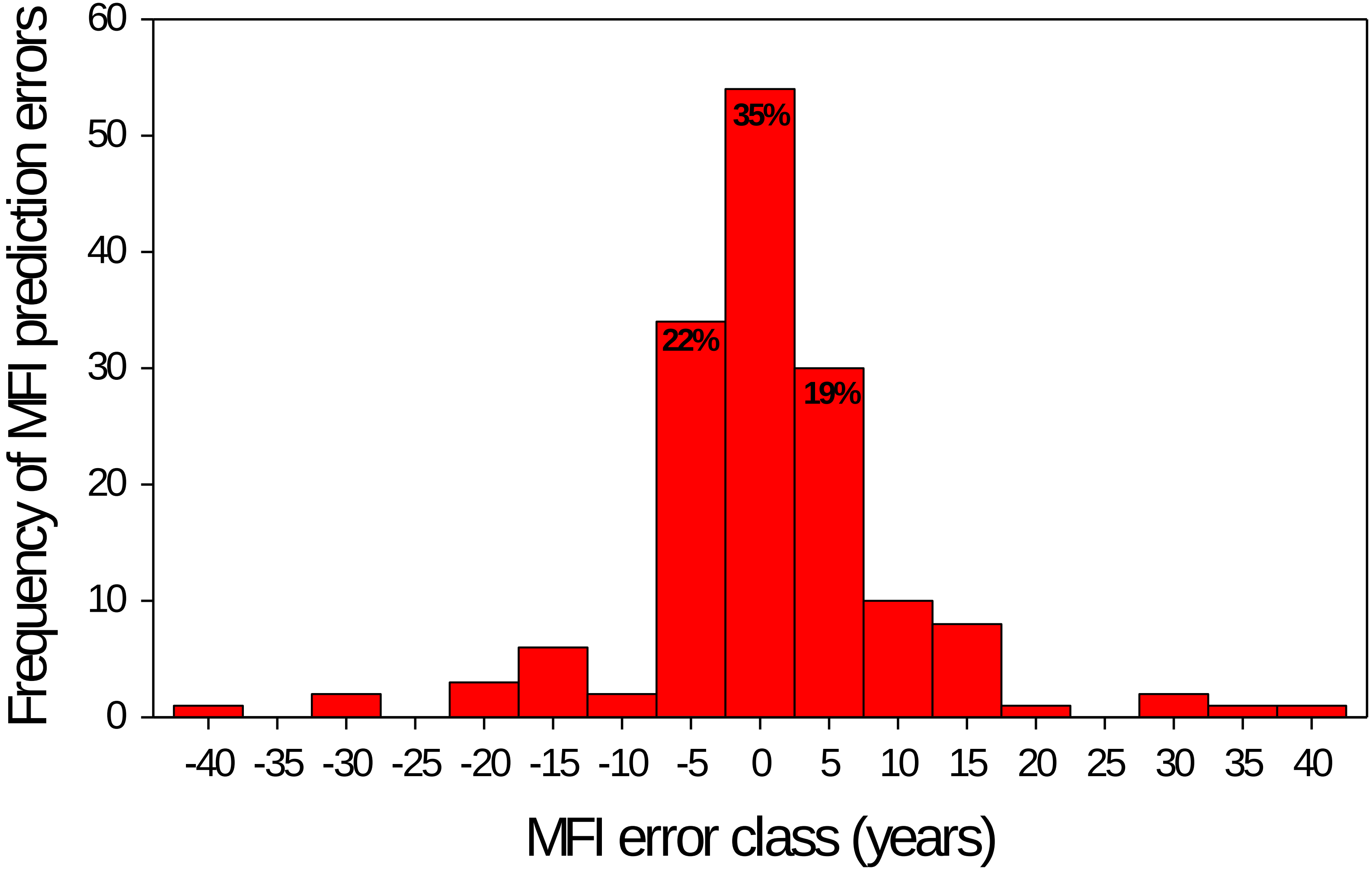




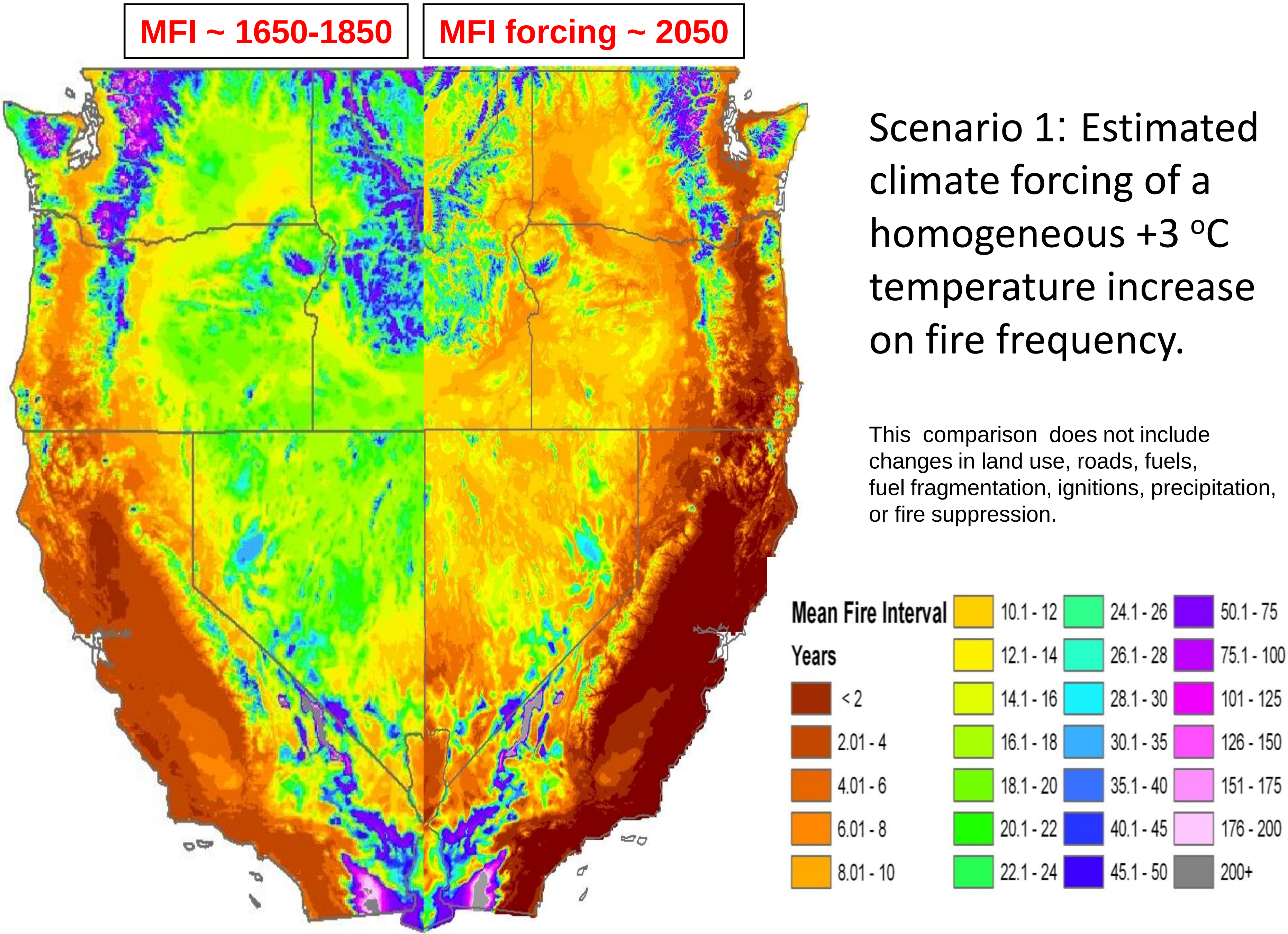
Fire frequency and Cherokee population at 3 sites in the Boston Mts. Arkansas

The 'tails' of the distribution have large random errors that occur when:

1) mean fire intervals (MFI) are very long,
2) data is qualitative (expert estimates),
3) stand replacement is the only known interval type for estimation.



Mirror images of past and future climate forcing of fire frequency (MFI)



Scenario 1: Estimated climate forcing of a homogeneous +3 ^{o}C temperature increase on fire frequency.

This comparison does not include changes in land use, roads, fuels, fuel fragmentation, ignitions, precipitation, or fire suppression.

Table 3. A spatial record of historic MFIs in the United States and three selected regions. Summaries of MFIs are based on arbitrary fire frequency ranges. Bold numbers are important differences among the 11,693,365 cells of 0.64 km^2 in area.

						Mean Fire Interval (yrs)					
						< 14 yr MFI		14 to 50 yr MFI		> 50 yr MFI	
Region	Area (km^2)	$\bar{x}$	Min	Max	σ	area (km^2)	% area	area (km^2)	% area	area (km^2)	% area
Continental U.S.	7483754	14.7	1	6728	31.6	3896372	52.1	3486360	46.6	101022	1.3
Eastern U.S.	3206317	12.2	2	249	7.5	1853761	57.8	1351382	42.1	1174	0.1
Great Plains	1704814	12.4	2	71	5.9	1013104	59.4	691645	40.6	65	0.0
Western U.S.	2572622	19.4	1	6728	52.7	1029507	40.0	1443332	56.1	99783	3.9

Note: areas do not include large lakes and coastal islands

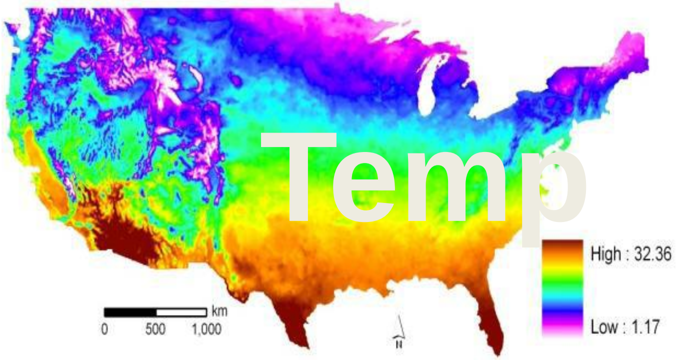
The PC2FM (Physical Chemistry Fire Frequency Model),

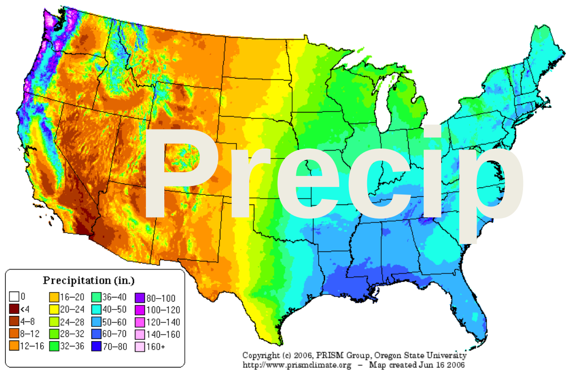
a mechanistic based model for predicting mean fire intervals

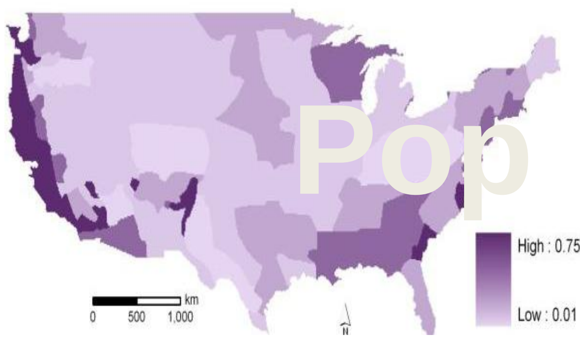
The process or mechanistic formulation for prediction:

$$\mathbf{MFI = C{*}exp}^{(-\ (0.139*\mathit{maxt}) + (1.50*\mathbf{moisti})\ -\ (2.41*\mathit{pop}) + (0.00763*\mathit{precip}))}$$

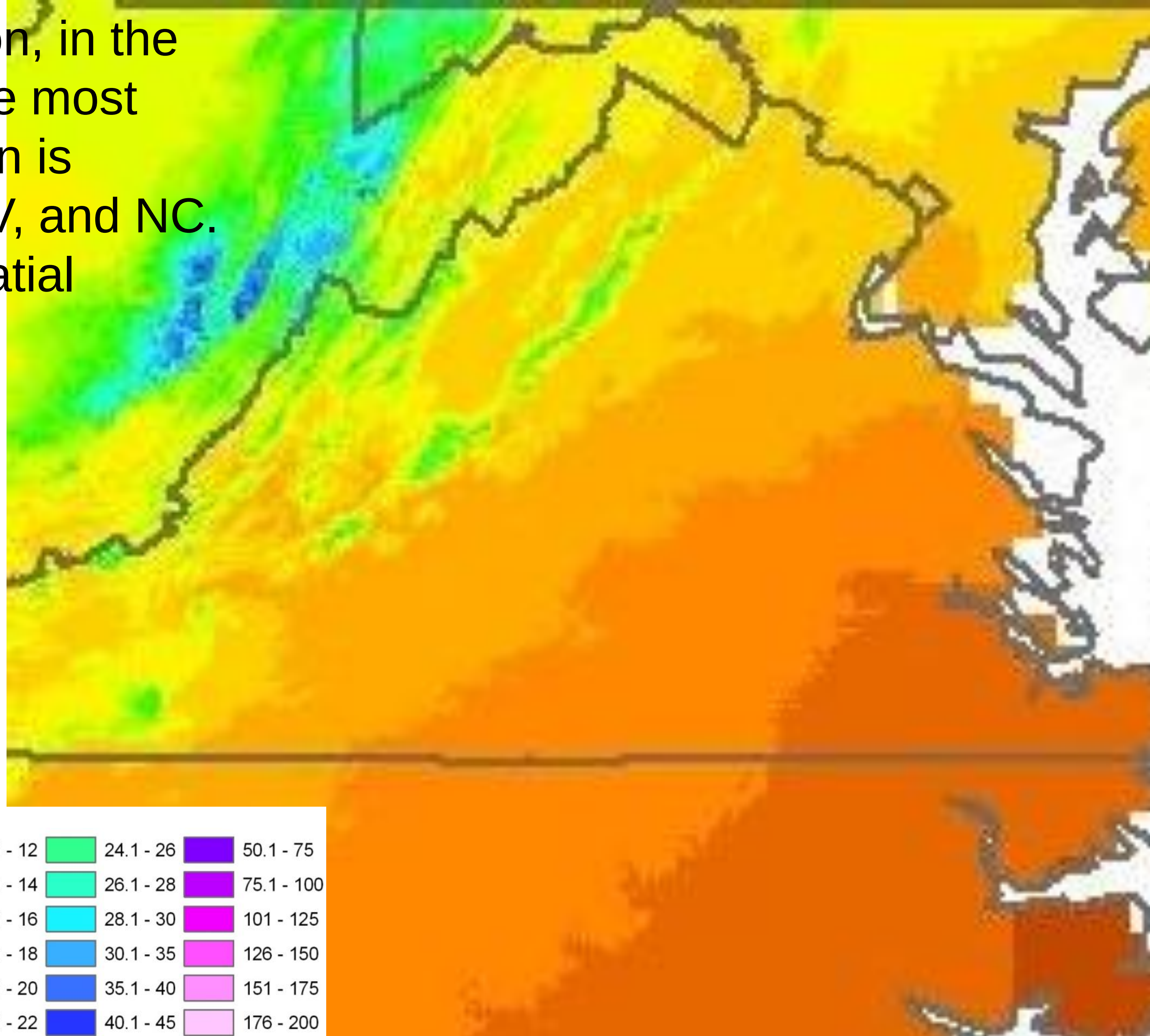
where: **MFI** is the mean fire interval (years),
C is a constant (59.12),
exp is 2.718,
maxt is average maximum temperature (^{o}C), partial $\mathbf{r^2}$ = 0.30
moisti the reciprocal of a moisture index 1/(***precip/maxt***), partial $\mathbf{r^2}$ = 0.23
pop is human population density (humans per km^2), partial $\mathbf{r^2}$ = 0.12
precip is mean annual precipitation (cm), partial $\mathbf{r^2}$ = 0.10
model $\mathbf{r^2}$ = 0.75, (tested)
period of calibration:~1650 and 1850 AD.
number fire history sites, model = 78, tested on 155 with replacement.







For comparison, in the eastern US the most complex region is across VA, WV, and NC. Here large spatial areas of MFI estimates and the MFI range is only of 70 years or less



Large differences in local scale fire intervals are masked by PC2FM mapping due to coarse scale climate data, population data, and the topography mitigation of fire regimes